EVALUATION OF SWINE LIQUID FEED SYSTEM WITH CORN-ETHANOL CO-PRODUCTS

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Abstract

Two experiments were conducted to evaluate the use of ethanol co-products, wet distillers grain (WDG) and condensed distillers soluble (CDS), in a swine liquid feeding system. The first experiment was conducted to evaluate the concentration of DE and ME and the apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of energy and nutrients in WDG and CDS fed to growing pigs. Six dietary treatments were studied by replacing 15% and 30% of a corn soybean meal basal diet with WDG or a mixture of WDG or CDS. The experiment consisted of 10 days of adaptation and 4 days of sample collection. Our results indicated that digestibility of 15% CDS diet was significantly higher ($P < 0.05$) compared to 30% WDG diet. DE and ME were higher in CDS compared to WDG. There was no significant difference in amino acid AID of diets. Lysine AID value of WDG was 75% which was higher than reported DDGS values. CDS lysine AID was 58%. Higher lysine AID could be because WDG was not exposed to drying, which reduces lysine digestibility in DDGS.

The second experiment was conducted to determine the ratio of WDG to CDS on the performance of wean to finish pigs fed via a computer-based automatic liquid feeding system. Four dietary treatments were compared by replacing 20% DDGS in the basal diet with same percentage (20%) of WDG or combination of WDG and CDS. Treatment 1, 20% DDGS, Treatment 2, 20% WDG, Treatment 3, 17% WDG + 3% CDS, and Treatment 4, 14% WDG + 6% CDS. The experiment was conducted from 2 weeks post-weaning to finishing (126 days on trial), using a 5-phase feeding program. The overall ADG was 0.912, 0.934, 0.957, and 0.937 kg/d, ADFI on a dry matter basis 2.47, 2.2, 2.26, and 2.24 kg/d, and gain to feed ratio 0.33, 0.37, 0.38, and 0.37, for Treatments 1 to 4, respectively. Overall ADG was higher ($P = 0.05$) in

Treatment 3 compared with the DDGS group. Overall, pigs fed diets containing WDG and/or CDS (Treatments 2, 3, and 4) had lower (P = 0.001) ADFI but higher G:F (P = 0.001) compared with animals fed the control diet containing 20% DDGS. Thus, WDG and the combinations of WDG and CDS have beneficial effect on growth performance compared with DDGS.

Keyword; Pig, liquid feeding, digestibility, growth performance

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List of abbreviations

AA	Amino acid
ADF	Acid detergent fiber
AID	Apparent ileal digestibility
Ala	Alanine
AOAC	Association of Official Analytical Chemists
Arg	Arginine
Asp	Aspartate
BW	Body weight
^{0}C	Degree Celsius
Ca	Calcium
CDS	Condensed distiller's solubles
cm	Centimeter(s)
cP	Centipoises
CP	Crude protein
Cys	Cystine
d	Day(s)
DDG	Distillers dried grains
DDGS	Distillers dried grains with solubles
DE	Digestible energy
DM	Dry matter
g	Gram(s)
GE	Gross energy
Glu	Glutamate
GLM	General linear model
Gly	Glycine
H	Hour(s)
His	Histidine
HPLC	High performance liquid chromatography
Ile	Isoleucine
kg	Kilogram
Leu	Leucine
Lys	Lysine

M	Meter(s)
ME	Metabolizable energy
Met	Methionine
MN	Minnesota
NC	North Carolina
NDF	Neutral detergent fiber
NRC	National Research Council
Pro	Proline
RFA	Renewable fuels resources
RPM	Revolution per min
SAS	Statistical analysis system
SEM	Standard error of the mean
Ser	Serine
SID	Standardized ileal digestibility
Thr	Threonine
Trp	Tryptophan
Val	Valine
WDG	Wet distillers grains

Chapter 1 Introduction

Application of swine liquid feed has been practiced since 1814 (Russell et al., 1996). Recently it has elicited great interest due to automation of liquid feeding systems. Swine liquid feeding is an emerging technology in North America, although it is common practice in other regions of the world especially in Western Europe and Brazil (de Lange and Zhu, 2004). Liquid feeding systems typically include a central feed mixing tank and a series of pumps and pipes to deliver liquid feed to individual feeding troughs. Liquid feed usually contains 20 to 30% dry matter content, and some liquid feed systems allow partial fermentation of ingredients, resulting in the production of organic acids and proliferation of beneficial bacteria, such as *Lactobacillus acidophilus* (Braun and de Lange, 2004; de Lange et al., 2006).

Traditionally liquid feed has been prepared and delivered by manually mixing dry feed with water. Advances in technology has improved automated feeding systems whereby liquid feed is prepared by mixing dry feed with co-products from food and/or ethanol plants and water. These ingredients are automatically mixed using a central mixing tank and delivered using high pressure air through pipes to feed troughs. Liquid feeding systems incorporate computer-based programs which allow producers to modify feed composition depending on the availability of feed ingredients. This application allows the flexibility to provide diets to meet the nutrient requirement of pigs through a multiple-phase feeding regime. There are several advantages of feeding pigs in liquid form as compared to dry form, such as improved gut health, use of inexpensive co-products from the food and bio-fuel industry, flexibility and ease of feed delivery, and manipulation of feeding value of ingredients with enzymes and microbial inoculants (Scholten et al., 1999; Brooks et al., 2001; Van Winsen et al., 2001). These benefits could improve growth performance and feed efficiency and reduce the reliance on in-feed antibiotics, which ultimately would reduce public concerns about in-feed antibiotics on pork production and pork products (Jensen and Mikkelsen, 1998; Brooks et al., 2001; Van Winsen et al., 2001). However, the majority of these benefits have been documented in European research where pigs are fed barley and wheat based diets, but the benefits may not be the same for pigs fed corn based diets (de Lange, 2012). Liquid feeding of newly weaned pigs using corn-based ethanol co-products has not been adequately studied. Most of the studies done in Europe were based on wheat and barley diets with liquid feed co-products sources mostly from food and dairy industries, and results have been variable. For example, Russell et al. (1996) and Kim et al. (2001) documented improved growth performance. In contrast, Lawlor et al. (2002) found no benefits of liquid feeding on the growth performance of newly weaned piglets.

Many studies have been conducted to investigate the efficacy of ethanol co-products in liquid feeding systems. However, no study has been performed to determine the optimal ratio of several ethanol co-products for liquid feeding. Ethanol plants produce wet and liquid co-products which are ultimately dried for use in dry feeding programs. Utilizing the wet feed could be an alternative in swine diets which could reduce cost of feed and labor. The objective of the first project was to determine the digestible energy, metabolizable energy (ME) and nutrient digestibility in wet distillers grains (WDG) and condensed distillers solubles (CDS) fed to growing-finishing pigs.

The objective of the second study was to determine the optimal ratio of WDG and CDS based on growth performance and carcass characteristics of pigs fed WDG, CDS and a combination WDG/CDS.

Literature review

1. Introduction

Weaning is a complex stage in the pig's life. It involves a transition of the young pig from a liquid diet, of around 20% DM, to a composite diet with around 85% DM usually offered in pelleted form (Brooks et al., 2001). In the wild pig, weaning encompasses a gradual transition from a liquid diet, exclusively based on sow milk, to a solid diet, over a period of 13 weeks post-partum (Lalles et al., 2006).

Modern commercial pig farms require efficiency for maximum production, and weaning is usually done within 14 – 28 days of age, which pose more challenges to the pig. The young pig starts to develop the capacity to digest non-milk feed ingredients between 2-4 weeks after birth (Whittemore et al., 2001). Low voluntary feed intake associated with poor growth after weaning is one of the major limitations to efficiency in pig production (Pluske et al., 1997). The newly weaned pig poses the principal management challenge on many pig production units. Even piglets that have been growing at 300 g per day, while suckling the sow often grow at half that rate, or less, in the week after weaning. Consequently, growth is compromised with negative or no growth (Brooks et al., 2001). An immediate reduction in growth rate of piglets after weaning, known as 'post-weaning growth check', is commonly observed in wean-finish pig production systems. This inhibition of piglet growth rate is associated with reduced feed intake (Bark et al., 1986; McCracken et al., 1995). Poor growth also leads to subsequent problems in the growing and finishing phases such as an increase in days to market and variation in performance.

Regardless of large volume of information from literature dealing with the nutritional, behavioral, health and environmental needs of the weaned pig, it is obvious that the post weaning growth check still represents a major production problem (Pluske et al., 1997). Noticeable changes that occur after weaning in the gut structure and function, include; villus atrophy and crypt hyperplasia, which associated with temporary decrease in the digestive and absorptive capacity of the small intestine (Pluske et al., 1997).

Liquid feeding has been reported to contribute to improved feed utilization, growth performance, and feed digestibility (Russell et al., 1996; Geary et al., 1998; Kim et al., 2001; Brook et al., 1996; Jensen and Mikkelsen, 1998). However, contrary results have been reported, that using liquid feeding has no particular benefits in growth performance (Lawlor et al., 2002; Pedersen et al., 2005; de Lange, 2006). Another suggested benefit associated with feeding diets in a liquid form is that piglets are provided with water and feed simultaneously (Brooks et al., 2001; Brooks and Tsourgiannis, 2003; Russell et al., 1996; Brooks et al., 2003a; Brooks, 2008). Thus, the piglets do not need separate training for feeding and drinking (Partridge and Gill, 1993; Russell et al., 1996). Some pigs may find a drinker within a few minutes after entering a pen, while others may take more than 24 hours, long enough to incur symptoms of dehydration (Barber, 1992). Providing the feed in a liquid form most often results in a higher feed intake after weaning (Russell et al., 1996). The optimal dry matter content of liquid feed varies with the pig's stage of growth, feed composition, and environmental conditions. In newly-weaned pigs, DM content of liquid feed should be maximized due to physical feed intake capacity, which limits nutrient intake (Geary et al., 1996; Russell et al., 1996).

A major ingredient in US Swine feed is corn. At present corn is increasingly being utilized for ethanol production in the Mid-Western US states, leading to increasing cost of pig feed. However, the use of corn in ethanol production also results in the generation of co-products that have the potential to be used for feeding pigs. One co-product of dry ethanol production is corn distiller's solubles. This co-product is added to wet distiller grains (WDG) to produce wet distiller grains and solubles (WDGS). WDGS is then dried to produce distillers dried grains and solubles (DDGS), to avoid deterioration in quality. However, the drying process is energy consuming. WDG and WDGS are usually used in ruminant feed (Ham et al., 1994).

Despite the nutritional advantages of the by-products of the ethanol industry, their inclusion in swine feed remains a big challenge owing to logistical and practical limitations of the existing mechanical swine feeding systems. One study at the University of Minnesota (Johnston et al., 2007) indicated the practical problems such as reduced flowability of using the by-products (DDGS) from the ethanol industry. It is also important to evaluate the performance and welfare of pigs fed these by-products in the liquid form before recommendations can be made for field use. Fresh CDS contain 30% dry matter and, on a dry matter basis, 22% protein, 19% fat, 8.4% ash, 1.4% phosphorus, 10% starch, and about 6% soluble sugars and the feeding value of CDS may be captured more fully, and drying costs, reduced when condensed CDS is fed in a liquid form to pigs (de Lange, et al., 2007). Wet distillers grain also contains 30 to 35% DM and fiber 44%, fat 15%, protein 30%, and minerals 3% on a DM basis (Weiss et al., 2007; Ham et al., 1994).

In various studies conducted at the University of Guelph, the feeding values of CDS, corn steep water (CSW) and whey permeate have been broadly evaluated. They reported that use of CDS and CSW had less effect on growth performance and carcass quality when used at 15% or less diet DM content, while whey permeate can increase growth performance at an inclusion rate of 20% dry matter content in phase II and Phase III nursery diets (de Lange et al., 2006). To best utilize liquid co-products from ethanol plants one has to consider better ways of delivering feed to the pig's trough. Nowadays specialized automated liquid feeding systems are being widely used in Europe. These systems are progressing in achieving efficient pig feeding, in relation to feed cost, management practices and overall production. However specialized liquid feeding equipment requires higher initial cost and ingredient storage capacity to utilize liquid feed ingredients (de Lange, 2012).

Therefore, liquid feeding is an alternative to dry feeding, which could have the potential to improve pig performance compared to dry feed. In this literature review potential benefits of fermented and non-fermented liquid feeding, and the co- products involved in this feeding system will be explored.

2. Liquid feeding

Liquid feeding creates an opportunity to increase the use of alternative feed ingredients from human food and biofuel industries. Liquid residues from these industries usually contain low dry matter and tend to have variable chemical composition between batches and among samples from different plants. Considering these factors during formulation, however, productivity and profitability can be maintained or even increased (Brooks et al., 2001).

Unlike the small holder farmer pig production in East Asia, liquid feeding application in intensive pig production requires suitable equipment in the modern units to maintain the feed in a hygienic and palatable condition (English et al., 1996). Many reviews of liquid feeding in pigs have been published in the past decade (Jensen and Mikkelsen, 1998; Brooks, 1999; Brooks et al., 2001). Results showed benefits of using liquid feed. However, based on growth performance of high health status pigs, corn-based diets fed to growing-finishing pigs have shown limited benefit of liquid feeding, in contrast to European, where swine liquid feeding research is focused on wheat and barley based feed (de Lange, 2012). These data suggest that liquid feeding dry ground corn is equivalent to feeding pelleted corn-based feeds. However, when comparing liquid feeding results from different research studies, it is crucial to consider liquid feeding practices such as soaking time, feeding management and feed wastage (de Lange, 2012).

2.1. Definition

It is important to define liquid feeding and differentiate it from other feeding systems, such as dry feeding, wet/dry feeding and paste feeding. Dry feeding is the common feeding practice for pig production using feed in mash form or pellet form, while wet/dry feeding enables feed and water to be available in the same feeder named single space wet/dry feeder (SSWD) with a nose-operated valve. However, paste feeding is the preparation of the diet in a feed - to - water ratio of 1:1 to 1:1.5 forming a paste material (Liptrap and Hogberg, 1992).

2.2. Utilization of liquid co-product

Liquid feeding reduces disposal cost of co-products thus maintain a cleaner environment in addition to the opportunities it provides (Scholten et al., 1999). Modern liquid feeding has been applied in Europe for more than one decade and continues to increase. The Netherlands provides the best example of co-product utilization, where it has been estimated that, about 6.5 million tons of co–products are used directly on farms annually (de Haas, 1998). Detailed data comparable to that from The Netherlands are not available from other countries, but using information from trade sources, it could be estimated at least 30% of all pigs in the EU are fed liquid diets and a majority of these incorporate at least some dairy by-products (Table 1.1; EFSA, 2006). Outside Europe, liquid feeding of swine has increased in North America, for instance in Ontario, Canada, where 20% of growing-finishing pigs are currently raised on liquid feeding system (SLFA, 2007).

Table 1.1 Pig numbers and estimated market shares of liquid feeding (dairy and other products) in some European Countries

		The share of liquid feeding	
Country	Pig no x 10^6	All pigs categories % fed	Sows % fed
Iceland	-	70	0
Denmark	13.4	60	30
Finland	1.4	60	20
Switzerland	-	50-60	30
The Netherlands	11.1	50	15
Ireland	1.8	40-50	20
Italy	1.9	40	5-10
Sweden	15.3	30	10
France	1.9	30	5-10
Austria	3.1	30	5-10
Germany	26.3	30	3-5
Norway	0.0	25-30	2
UK	4.8	20	10
Belgium	6.3	10	2
Greece	1.0	10	2
Spain	25.4	1	-
Portugal	2.3	-	-
EU-25	151.6	30	-

(EFSA, 2006)

Variability in the nutrient values of co-products is an issue to nutritionists while formulating diets (Brooks, 2001). Scholten et al. (1999) investigated the inclusion of a combination of liquid wheat starch (LWS), potato steam peel (PSP) and cheese whey (CW) in pig diets, having same energy content and nutrient levels. The results showed that it was possible to include 35% and 55% of these co-products on a DM basis in growing and finishing pigs, respectively, at a water to feed ratio of 2.6:1 without compromising growth performance. Braun and de Lange (2004) also reported higher variability with corn co-products and suggested frequent sampling and analysis in order to enable accurate formulation of diets. Additionally co- products tends to have high mineral content, so it is necessary for the pigs to be provided with additional free access to water, to maintain their homeostatic balance (Brooks and Carpenter, 1990).

Usually, farms adopting liquid feeding systems tend to be centered near areas where liquid co-products from food industries or biofuel industries are readily available, thus reducing the transportation cost and improving profit. Moving liquid co-products long distances could be expensive.

2.3. Design of modern liquid feeding system

Brooks (1999) described modern liquid feeding system as; computer controlled, capable of preparing diets from dry and liquid components with the flexibility to prepare any number or variety of meals per day or feed pigs *ad libitum* change any or all the parameters from one batch mixing to the next.

There appears to be many liquid feeding systems used around the globe, ranging from simple manual to automatic mixing and delivery systems. Automatic feeding systems are equipped with computer controlled feed preparation and delivery systems, and sensors which control feed delivery (Columbus *et al.,* 2006; Big Dutchman, 2012). According to de Lange (2012), automated feeding system requires computer and engineering skills that differ, based on your ingredient choice or condition of the farm. However there are some common aspects to most commercial liquid feeding systems such as;- (1) a central feed mixing tank and residue tanks to separate different batches of feed, (2) tanks for controlled steeping or fermentation of liquid feed ingredients or mixed liquid feeds, (3) delivery of liquid feed to feeding troughs and (4) design of feeding troughs.

A key feature of an automated liquid feeding system is to have absolute control and monitoring of feed intake and feeding programs. Practices such as split-sex feeding, phase or blend feeding, introduction of new (liquid) feed or modest feed intake restriction prior to slaughter, are easily implemented when using modern liquid feeding systems. Moreover, sudden feed intake changes related to onset of disease can be identified rapidly. Installation of a liquid feed system would solve these limitations and be economically viable in reducing feed cost (de Lange, 2012).

3. Liquid versus dry feeding

The European liquid feeding system mostly depends on fermented liquid feed, which has benefits compared to dry feeding in swine production. These benefits include improved nutrient utilization, flexibility and control of feeding programs, utilization of inexpensive liquid by-products, reduced environmental impact, and improved animal performance (Jensen and Mikkelsen, 1998; Russell et al., 1996; Canibe and Jensen, 2003; Brooks et al., 2001). Liquid feeding may also enhance gut health, lessen the need for feed medications, and improve animal well-being (Brooks et al., 2001; Canibe and Jensen, 2003). Several studies have reported food safety benefits as well in terms of a lower *Salmonella* seroprevalence in blood samples of finisher pigs fed on liquid feed compared to pigs fed on dry feed (van der Woolf et al., 2001; MLC, 2004; Farzan et al., 2006).

Other studies have also indicated health benefits of liquid feeding. A study by Scott et al. (2007) reported that liquid feeding of grow-finish pigs lowered gastric ulcer scores at slaughter compared to dry pellet feeding and other authors also reported that ileal, cecal and colon digesta samples from liquid fed pigs had lower coliform ratios, indicating improved gut health (Hillman et al., 2004; MLC, 2004).

Brooks et al. (2001) summarized the advantages of liquid feeding as follows;

- Reduction of feed cost
- Improvement in the pig's environment and health due to the reduction of dust in the atmosphere
- Improved pig performance and feed efficiency
- Flexibility in raw material use thanks to utilizing more economic liquid co-products
- Improved material handling (system can act as both a feed mixing and distribution system)
- Increased accuracy of rationing (computer control brings a degree of accuracy to the system that is difficult to emulate with dry feeding systems)
- Improved DM intake in weaned pigs and lactating sows
- Improved feed intake at high ambient temperature

The benefits of liquid feeding over dry feeding have been long been established. Braude (1972) reviewed 61 studies and concluded that wet feeding was superior to dry feeding in most studies with the exception of just a few which found no differences in performance. Other studies reported from 1972 to 2004 which are summarized in table 1.2 showed the advantages of liquid feeding over dry feeding in ADG and F: G ration.

Table 1.2 Comparing liquid feeding versus dry feeding for pigs growth performance and carcass quality.

Average daily gain	Feed-gain ratio	Carcass quality	Reference
+	+	0	Kneale, 1971
+	+	0	Smith, 1976
+	0	NF	Bradue and Newport, 1977
+	NF	NF	Lecce et al., 1979
0	-	NF	Kornegay et al., 1981
+	+	-	Patterson, 1989
+	+	NF	Patridge et al., 1992
+	+	NF	Upton, 1993
+	+	NF	Pluske et al., 1996a
+	+	NF	Pluske et al., 1996b
+	+	NF	Kim et al., 2001
0	0	NF	Lawlor et al., 2002
+	0	NF	Canibe and Jensen, 2003
+	-	NF	Choct et al., 2004b

Note + Liquid is better ; - dry is better ; 0 No difference ; NF No information

4. Common Co-products from Food industries used in Liquid Feeding Systems

Liquid feeding for swine diets can use ingredients from a wide range of sources such as food industries, milk processing, and candy, bakery and alcohol production products. Limited nutritional information is available for some products, and there is concern on their variability of contents. Many products also have not been evaluated for pathogens or harmful chemicals and may represent a food safety risk (Brooks et al., 2001). The following co-products have been used in pig production in different countries and are potential ingredients for use in liquid feeding system.

4.1. Liquid Whey

Whey is the by-product from cheese production (Crawshaw, 2001). One unit of cheese and 9 units of whey are produced from every 10 units of whole milk. Whey typically has a pH of 5. If it has not been treated with excessive heat, whey contains highly digestible protein and is an excellent, highly digestible energy source for young pigs, because it contains approximately 60% lactose. However, due to the decreasing ability of the pig to effectively digest lactose after weaning, digestive upset can occur in older pigs when it is included in liquid feed or fed at high dietary levels. Additional access of water should also be provided to avoid salt toxicity due to high salt content (Braun and de Lange, 2004).

4.2. Brewer’s Wet Yeast (BWY)

Fresh brewer’s yeast is produced by removal of the culture from the fermenting beer wort by flocculation or sedimentation. After separation of yeast from beer, it will have 30% DM, after pressing to remove any remaining beer. Brewer’s yeast contains active yeast which may cause further fermentation and frothing during storage the buildup of pressure in liquid feed lines and bloating of pigs As a result, organic acids should be added to deactivate yeast or heating should be applied to kill live yeast prior to shipping (Ruis, 2003).

Fresh brewer’s yeast is an excellent source of protein of high biological value and digestibility. It is high in B complex vitamins, and a rich source of enzymes and cofactors that can be fed to pigs to enhance productivity (Kornegay et al., 1995). It is usually added at a rate of 2-5% in swine diets but can be used to replace up to 80% of the protein if it is inexpensive. Good growth performance can be achieved when feeding wet brewer’s yeast but the response varies with the stage of production when it is fed (Van Heugten et al., 2003; Braun and de Lange, 2004).

4.3. Sugar Syrup

Sugar syrup contains approximately 65% DM and is high in energy but essentially low in protein, vitamins, and minerals. High sugar content can cause digestive upsets in pigs and therefore, should be limited to no more than 5% of the diet (de Lange et al., 2006).

4.4. Bakery Waste

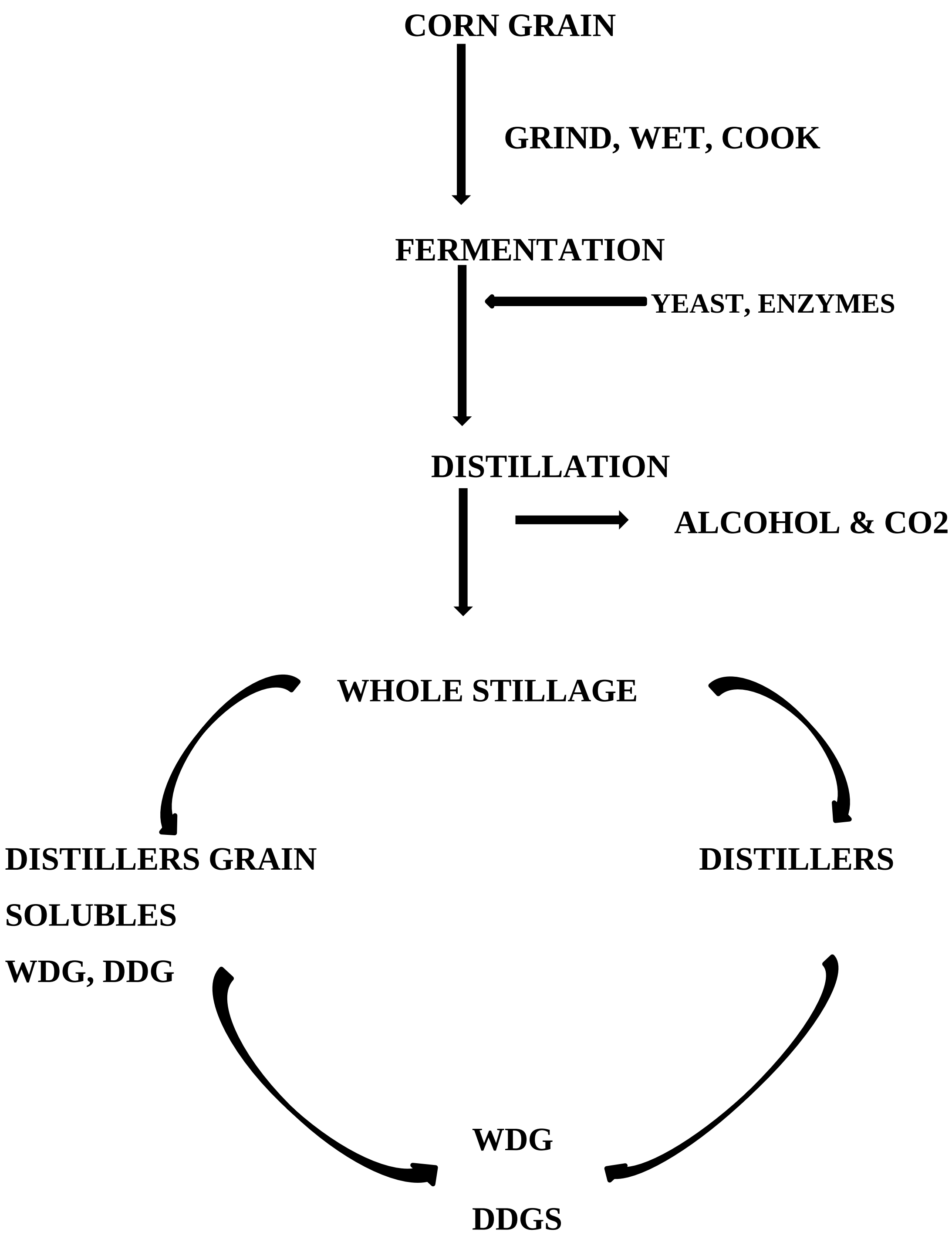
Bakery waste includes bread, cookies, crackers and other confectionaries and can vary markedly in nutrient content depending on the type of food by-products in the mixture. Bread is high in energy but may require special handling equipment to remove wrappers. Bread meal should be limited to no more than 30% of DM intake for pigs. Cookies and crackers can contain high amounts of fat and sugars making them excellent energy sources. Depending on the type of bakery product, salt content can be relatively high and should be taken into account when formulating the liquid feed supplements. It is usually about 90% dry matter, 10% protein, <1% crude fiber and 3-5% ash. It can replace all grain in the swine diet (de Lange et al., 2006).

5. Liquid Co-products from the Ethanol Industry

Ethanol co-products can be generated from several sources, including grains (corn, sorghum, barley, wheat, etc.), lignocellulosic-biomass (wheat straw, corn stover, switch grass), or from other sources like sugar cane (Klopfenstein et al., 2008). In the US, corn grain is used to produce ethanol as it is good source of starch for fermentation (Klopfenstein et al., 2008).

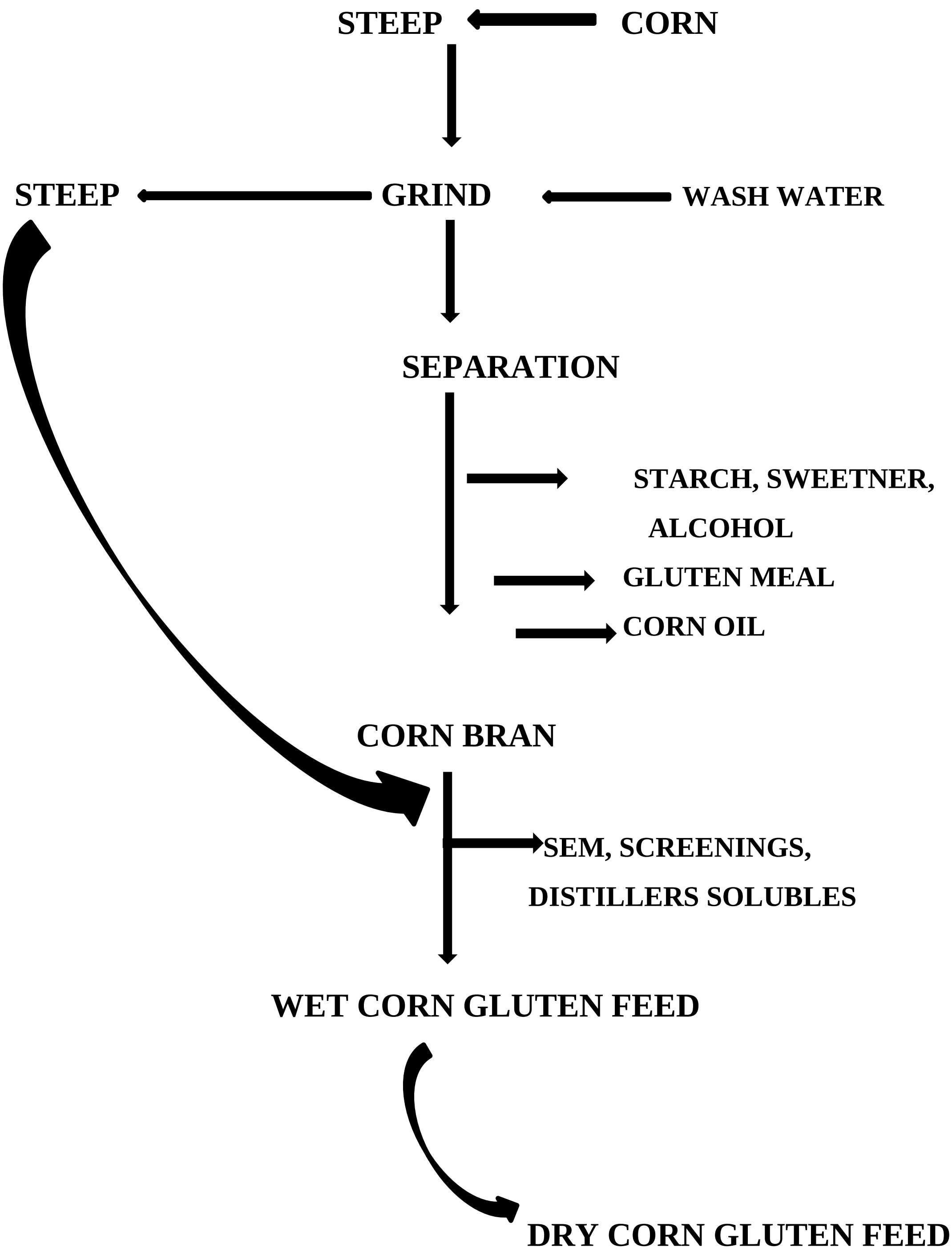
Currently in U.S there are two ethanol production processes, dry-grind and wet mill production. The majority of ethanol produced today is from dry-grind ethanol plants, which constitute 82% of ethanol production, whereas, wet milling, constitute 18% of ethanol production (RFA, 2007). The dry-grind production process (Figure 1.1) consists of a relatively simple sequence of procedures, including grinding, cooking, liquefying, saccharifying, fermenting and distilling to produces ethanol, distillers grains and carbon dioxide (Rosentrater and Kongar, 2009). The byproducts from dry grind include wet distillers grain, condensed distillers solubles (CDS), modified wet distillers grain, dried distillers grain (DDG), and dried distillers grain with solubles (DDGS) (Shurson, et al., 2012). Distiller's grains are good sources of both protein and energy, because, the nutrients remaining after extraction of starch are concentrated threefold (Klopfenstein, 1996; Klopfenstein et al., 2007). The wet milling production process (Figure 1.2) is a complex process designed to recover and purify starch and several co-products, and produces ethanol, corn gluten feed, corn gluten meal, steep water, corn germ meal, crude corn oil and condensed fermented extractive (Ramirez et al., 2008; Shurson et al., 2012).

Figure 1. 1 Dry grind ethanol production process and co-products



(Erickson et al., 2012)

Figure 1. 2. Wet milling ethanol production process and co-products



(Erickson et al., 2012)

According to Shurson (2006) “Ethanol plants prefer to market wet by-products due to rising fuel costs and challenges associated with drying the condensed solubles. On the other hand, U.S. pork producers are searching for ways to reduce feed costs due to record high feed ingredient prices. As a result, U.S. pork producers are beginning to use liquid feeding systems to utilize relatively low cost liquid by-products from the ethanol industry”. Among the cheaper co-products from ethanol plants, the two major liquid co-products from both dry grind and wet milling are CDS and CSW, which are typically dried and included in DDGS and corn gluten feed, respectively (Fontaine et al., 2007). These liquid co-products have been evaluated for use in swine liquid feeding systems (de Lange et al., 2006). According to Braun and de Lange (2004), CSW contains approximately 50% CP and 3.3% P, 0.5% oil (Table 1.3); whereas CDS contains 18.9%, 22.3% CP and 1.43% P. CSW is markedly higher in CP and phosphorus than CDS. However, nearly 80% of the phosphorus in corn steep water is bound as phytate and hence inaccessible to pigs unless phytase enzyme is added to improve digestibility. Besides, CSW is noticeably lower in energy than CDS due to the low fat content.

Table 1.3 Nutrient compositions of condensed distillers soluble and corn steep water (100% DM basis)

Item	Corn CDS	Corn Steep Water
N(trials)	5.0	3.0
Dry matter, %	30.5	45.0
Crude protein, %	22.3	50.0
Crude fat, %	18.9	0.5
Ash, %	8.4	18.0
Ca,%	0.04	-
P,%	1.4	3.3
Na,%	0.2	-
K,%	-	5.0
pH	3.7	4.3

Source based on (Braun and de Lange., 2004) and (Niven et al., 2006)

5.1. Corn Distiller Solubles (CDS)

Corn distillers soluble is a liquid co-product of corn distillation through yeast fermentation of mash corn. During the fermentation process, the corn starch granules are almost entirely converted to alcohol and carbon dioxide. The mash remaining after the fermentation process is centrifuged and most of the liquid is removed. The remaining liquid is the distiller solubles and thin stillage. The liquid is either dried or condensed. Generally the dried product is included with corn distiller grains (Shurson, 2004). The condensed product is the CDS, which is rich in fat, protein, minerals and vitamins. CDS may contain yeast cells and other unidentified nutrients resulting from the fermentation process. Typically, CDS is about 30% DM, 18.7% protein and 12.07% fat, ash 8.7% on a dry matter basis (NRC, 2012). There is very little research on this product. Squire (2005) reported reduced feed palatability in growing pigs when CDS inclusion was more than 15.0%. Poor palatability was believed to improve following inoculation of CDS with lactobacillus or other (Squire, 2005).

In a grower pig performance study (Table1.4), feeding non-fermented CDS resulted in significant reduction in growth performance; while pigs fed the fermented product did not differ from the controls (Squire et al., 2004). Fermented CDS apparently provided more beneficial lactic acid and lactic acid bacteria (LAB) to the pigs, which improved feed and nutrient utilization (Squire et al., 2004). The digestibility of energy and protein was slightly reduced in pigs fed fermented CDS but, digestibility of fat was increased in pigs fed CDS containing diets, indicating that fat in CDS is highly digestible (Squire et al., 2004).

Table 1.4 Growth performance and nutrient digestibility of piglets fed liquid diets fed CSBM with 15% fermented and non-fermented CDS (DM basis)

	Control	Non-fermented CDS	Fermented CDS
No. Pens	6.0	6.0	6.0
Initial body weight, kg	23.5	23.3	23.4
Final body weight, kg	50.1[a]	47.5[b]	48.6[ab]
ADG, g/d	952[a]	858	898
ADFI kg/d	1.6[a]	1.5[b]	1.6[a]
Feed: Gain	1.7	1.7	1.8
Energy digestibility,%	81.6[ab]	82.5[a]	79.9[b]
Protein digestibility, %	80.9[b]	85.4[a]	85.4[a]

[ab,]Means within a row without common superscripts differ (*P* < 0.05).

Source: de Lange et al, (2006)

5.2. Wet Distillers Grains (WDG)

Once fermentation of corn-starch is complete ethanol and carbon dioxide (CO_2) are produced. Ethanol is distilled and the remaining liquid is centrifuged. The residue left after centrifugation is called WDG. This distiller's grain contains of 30 to 35% dry matter (DM), fiber (44%), fat (15%), protein (30%), and mineral (3%) (Weiss et al., 2007; Ham et al., 1994). Due to its high moisture level WDG has high risk of molding during storage, hence avoiding longer storage times and addition of preservatives could minimize molding.

Thin stillage (5 to 10% DM) which comes after the centrifugation step is evaporated to produce condensed distiller's solubles (CDS) are then added to WDG to produce wet distillers grains with solubles (WDGS, 30 to 35% DM) (Stock et al., 2000) or dried to produce DDGS. The drying process, however, increases the energy costs incurred by the ethanol plant and may produce changes that reduce the nutritional value of the product (Kinman et al., 2011). There is little information available on the use of WDG in swine feed, but, it has been effectively used as a protein and energy source for ruminants (Firkins et al., 1985, Ham et al., 1994). From an ongoing preliminary experiment done at the University of Minnesota, Baidoo et al. (2014) observed positive results in growth performance on pigs fed 25 - 30% WDG. Despite the benefits derived from these co-products, WDG typically have the tendency to deteriorate (DM loss) within a short time during storage. Nevertheless, research has suggested that high moisture distiller's grains have higher energy value per unit dry matter than dried distiller's grains (Loy and Strohbehn, 2007).

5.3. Corn Steep Water (CSW)

Pigs may utilize nutrients in steep water more efficiently. On analysis, CSW was found to have a pH of 4.3, contain 45% DM and, on a DM basis, 50% crude protein, 2% lysine, 18.0% ash, 5% potassium, 3.3% phosphorus (about 80% of which is bound in phytate), 1.5% magnesium, 0.5% crude fat and 20% lactic acid (Niven et al., 2006c). In a preliminary study Niven et al. (2006) reported that growth rate and feed conversion ratio were numerically improved after pigs were fed liquid diets containing 5% CSW, while 10% CSW numerically reduced their performance. In a larger study, de Lange et al. (2006) showed that when pigs were fed liquid diets containing 0, 7.5, or 15% phytase treated CSW, average daily gain, average daily feed intake, and feed: gain were not significantly affected, but adding 22.5% CSW resulted in reduced performance (Table 1.5). According to de Lange et al. (2006), no significant effects were observed for dietary inclusion level of CSW for carcass weight, loin depth, backfat depth, and lean yield.

Table 1.5 Growth performance and carcass characteristics of piglets fed different level of liquid CSW

	0% SW	7.5% SW	15% SW
No. of pens	4	4	4
Initial BW., kg	69.1	68.8	68.8
Final BW., kg	108.3	104.6	107.7
ADG, g/d	1191[a]	1080[a]	1063[a]
ADFI kg/d	2.76[a]	2.49[ab]	2.58[ab]
Feed : Gain	2.33[a]	2.30[a]	2.42[ab]
Carcass wt., kg	86.3	82.7	83.4
Loin depth, mm	58.2	58.9	56.4

[a,b]Means within rows with different superscript differ ($P < 0.05$).

Source: (de Lange et al., 2006)

6. Fermentation of liquid feed (FLF)

The use of microbial fermentation to conserve or improve food is one of the oldest ways of food processing and preservation. Human population around the world have used microbes to prepare food products for thousands of years and majority have wide range of fermented foods and beverages which contributed significantly to their diet (Achi, 2005).

Generally fermented food has a longer shelf life than its original substrate (Adams and Mitchell, 2002) owing to the antimicrobial properties generated from the fermentation process. By definition, fermented liquid feed (FLF) is a feed mixed with water at a ratio of 1:1.5 to 1:4 and fermented to reach a steady condition (Brooks, 2003). It is usually prepared by spontaneous fermentation or inclusion of starter culture of LAB as inoculants in the feed.

6.1. Desired properties of FLF

When feed is soaked in water for a certain length of time, lactic acid bacteria and yeasts naturally occurring in the ingredients proliferate and produce mainly lactic acid and acetic acid, which reduces the pH of the mixture ultimately preventing the proliferation of spoilage organisms and foodborne pathogens (Nout et al., 1989; Russell and Diez-Gonzales, 1998; van Winsen et al., 2001a). *Enterobacteriaceae* are usually active when incubated at 20^{o}C and reach maximum level at 24 h, but with decreasing pH their level decreases as a result of increasing organic acids (Canibe and Jensen, 2011). FLF is assumed to be best when the fermentation, spontaneous or induced, yields stable and high numbers of LAB, stable and low pH (3.5–4.5), and consequently low or nonexistent *Enterobacteriaceae* population (Geary et al., 1999; Brooks et al., 2003; Plumed-Ferrer et al., 2005).

According to Canibe and Jensen (2003), the initial phase of fermentation is characterized by low levels of LAB, yeasts, and lactic acid, high pH, and, importantly, a blooming of enterobacteria. This phase is followed by a second phase, in which a steady state is reached, and also characterized by high levels of lactic acid bacteria, yeasts, and lactic acid, low pH, and low enterobacteria counts. Van Winsen et al. (2000) also showed that lactic acid is the main organic acid responsible for the antimicrobial effect of FLF. A fermentation product dominated with yeast is not desirable because it reduces feed intake (Plumed-Ferrer et al., 2008). Due to the production of high mixtures such as acetic acid, ethanol and amylic alcohols, FLF might have an unpleasant odor and/or taste (Brooks et al., 2003a; Canibe et al., 2007). Jensen and Mikkelsen (1998) found an inverse relationship between the concentration of yeast and enterobacteria in the gastro intestinal tract (GIT) of pigs. Therefore, high concentrations of yeasts in the FLF may also be beneficial. However, the population diversity of yeasts present in FLF is very high and deserves further investigation (Olstorpe et al., 2008).

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6.2. Effect of Fermented Liquid Feed (FLF) on GIT health

There is growing evidence that liquid feed reduces gastrointestinal disorders and diarrhea. This appears to reduce the prevalence of *Salmonella* (Tielen et al., 1997; Pedersen et al., 1998; Braun and de Lange, 2004). Feeding FLF to piglets has been suggested as an approach to maintain high and consistent feed and water intake in the critical period after weaning. The fermentation of a liquid diet has been reported to affect the physiology, microbiology and morphology of the GIT (Van Winsen et al., 2001b; Scholten et al., 2002; Canibe and Jensen, 2003). Feeding a liquid diet to pigs results in a reduction in pH and increases lactic acid and volatile fatty acids (VFA) concentrations in the gastric digesta, as well as a decline of e*nterobacteriaceae* all along the GIT, and in an improvement in villus / crypt ratio (van Winsen et al., 2001b; Scholten et al., 2002; Canibe and Jensen, 2003).

Pedersen et al. (1998) examined the relationship between pH and temperature of liquid feed on the incidence of diarrhea. They highlighted that a higher incidence of diarrhea in herds occurred when the pH was above 4.6. The low pH of 3.5-4.5, along with high levels of lactic acid was associated with lower diarrhea incidence. These authors attributed the effect of suppressing *Salmonella* prevalence to the antimicrobial effect of the organic acid, mostly lactic acid, present in the liquid residues or FLF resulting from the fermentation process by LAB. From the aforementioned information liquid feeding has a positive effect in GIT health and reduces incidence of *Salmonella*. In the Netherlands, for instance, it was found that farms on liquid feeding had 10 times lower incidences of *salmonella* than farm with dry diets (Tielen et al., 1997). This effect had been associated with fermentation of the co-products by lactic acid bacteria resulting in lower pH due to significant quantities of lactic acid which inhibits proliferation of *Salmonella* in feed (Brook et al., 2001).

7. Water to feed ratio

An important feature of a successful liquid feeding system is the water to feed ratio of the diet. This affects the DM content of diet and may also influence the intake and organic acid concentration of the feed. Research to confirm the ideal DM content of liquid diets is limited (Choct et al., 2004a). Generally, the water to feed ratio of LF or FLF can fluctuate between 1.5:1 and 4:1. A growing body of literature has demonstrated the importance of water to feed ratio (Gill et al., 1987; Barber et al., 1991). Barber et al. (1991) as presented in Table 1.6 reported that DM digestibility increased linearly with the increasing water to feed ratio from 2:1 to 4:1.

Table 1.6 Effect of water to feed ratio on diet digestibility

	Water to feed ratio			
	2 :1	2.67: 1	3.33:1	4 :1
Dry matter digestibility (%)	79.1[a]	77.8[a]	80.3[a,b]	82.9[b]
Estimated DE (MJ Kg^{-1}) DM	15.1	14.9	15.4	15.8

[a,b]Means within a row without common superscripts differ ($p < 0.05$).

(Barber et al., 1991)

Gill et al. (1987), also reported that decreasing water to feed ratio also had a beneficial effect on growth rate and feed conversion ratio. It has been suggested that the change of water to feed ratio results in a reduction of viscosity of the digesta, and hence, allows for more contact between digesta and digestive enzymes (Brooks, 1999).

Geary et al. (1996) also studied the performance of weaner pigs fed *ad libitum* a diet mixed with water to provide four different DM concentrations of 149, 179, 224 and 255 g kg^{-1}, over a four week period post-weaning. They concluded that weaner pigs would readily accept liquid feed with DM content in the range 255 to 149 g kg^{-1} and piglets on liquid diets were able to control dry matter intake through increasing total volumetric intake and regulation of their voluntary water intake from nipple drinkers.

8. Effect LF on growth performance

Liquid feed has been seen to improve growth performance (Scholten, 1999). Kim (2001) also reported an improvement in DM intake and nutrient utilization. An increase in average daily feed intake is also associated with an increase in average daily gain. Jensen and Mikkelsen (1998) concluded that liquid feeding of newly weaned pigs resulted in 12% increase in ADG in comparison to dry feeding based on a review of several studies. Improving feed intake during the post-weaning period is very important in enhancing development of the small intestine and subsequent growth performance and in maintaining gut integrity and villus height (Deprez et al., 1987; Pluske et al., 1997), thereby preventing the “growth lag” associated with weaning. However, feed to gain ratio was worse for nursery pigs fed LF or FLF compared with dry feed. The poor gain to feed ratio was attributed to increased feed wastage from poor trough design (Russell et al., 1996).

However, Lawlor and Lynch (1999) reported that even with an improved trough design, weaned piglets fed FLF or LF still had a significantly lower feed conversion ratio compared with those fed dry feed. Originally, one of the major advantages of LF or FLF is that it enables the use of food industry liquid co-products and biofuel co-products. Scholten et al. (1999) have demonstrated that pigs fed liquid diet containing fermented co-products showed a significant improvement on average daily gain and feed conversion ratio compared to pigs on non-fermented liquid diet.

Another study involving 1024 pigs, (MLC, 2004) showed that *ad libitum* liquid feeding improved average daily gain (ADG) and feed conversion ratio (FCR) by 5.6 and 10.3% respectively, with no adverse effect on carcass characteristics.

Most of previous research showing better performance of pigs fed liquid feeding than dry feeding used wheat and barley based diets. According to de Lange (2006), in a growing-finishing pig performance study, conventional dry feeding was compared to liquid feeding of dry corn or high moisture corn based diets (Table 1.7). Growth performance advantage of liquid feeding was not observed. However, feed efficiency was about 5% better when pigs were fed high moisture corn. This was in contrast to the studies at Stotfold research station from UK (MLC, 2005). These contrasting findings were related to the liquid feeding equipment (de Lange et al, 2006). At the Stotfold unit, mixed feed was soaked in water in a mixing tank for several hours prior to delivery, while in the Big Dutchman Hydrojet system, feed was dispensed to the troughs within minutes after feed preparation. As previously mentioned benefit of liquid feeding may be smaller for corn-based diets than wheat and barley-based diets. Soaking may benefit more fibrous ingredients with endogenous phytase activity such as wheat and barley (de Lange, 2006). Hence more research on this subject could unveil the advantages that may be available in corn based co-products.

Table 1.7 Impact of feeding strategy on performance of growing finishing pigs

	Conventional feeding dry pellet feed	Liquid feeding dry corn	Liquid feeding high moisture corn
Initial BW (kg)	23.5	23.7	23.4
Final BW (kg)	104.7	105.8	104.2
Gain (kg/d)	982	1011	1009
Feed : Gain (88% DM)	2.63	2.64	2.51
Carcass dressing (%)	82.2	80.4	82.5
Carcass lean yield (%)	61.2	60.9	61

Source (Columbus et al, 2006)

9. Conclusion

Liquid feeding has a potential advantage for feeding pigs, especially young piglets, which are susceptible to stress soon after weaning. Growth check is a phenomenon where pigs face significant growth lag seen after weaning and is common on commercial farms. Liquid feeding has been reported to alleviate the nutritional stress occurred due to sudden change of liquid diet which is milk to dry diet. Most of the research on liquid feeding has been done in Europe with wheat and barley diets, and indicates benefits with respect to their production systems. With the adoption of automatic swine liquid feeding system in Europe there had been tremendous value in the swine production, especially after the ban of antibiotics use in Europe. The liquid system has been helpful in improving management and health status of pigs. In addition, they have been using cheap co-products from food industries, candy manufacturing, milk processing (whey, butter milk) and beakers and beverage industries.

So far in North America, liquid feeding is at its rudimentary stage. Some efforts have been made recently in Ontario, Canada in 2004 to introduce liquid feeding to farmers. This has resulted in about 20% of grow to finish pigs being raised on liquid feed. In the US Mid-west in IA and MN, it is gaining interest due to increasing price of corn. With the increasing production of ethanol co-products (liquid / wet) there is greater potential to introduce and exploit the benefit of using liquid feed which ultimately may reduce cost of feed and increase production and profit.

Chapter 2

Determination of energy and nutrient digestibility of corn-ethanol co-products (WDG and CDS) in growing pigs

Summary

An experiment was conducted to determine the concentration of DE and ME and the apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of energy and nutrients in wet distillers grains (WDG) and condensed distillers soluble (CDS) fed to growing pigs. A total of 36 crossbred barrows (Topigs × Comparts Duroc) were selected with average initial body weight of 42 ± 1.8 kg. Pigs were allotted to 6 dietary treatment groups using a complete random block design. Dietary treatments included: 1) corn-soybean meal basal diet (CSBM); 2) CSBM + 15% WDG; 3) CSBM + 30% WDG; 4) CSBM +15% CDS; 5) CSBM + 30% CDS; 6) CSBM + 15% CDS + 15% WDG on a DM basis. DE and ME were higher in CDS than in WDG. The AID of lysine, methionine, threonine, and tryptophan was 75%, 74%, 75%, and 78% in WDG, and 58%, 41%, 50%, and 48% in CDS, respectively. In conclusion liquid/wet ethanol co-products could serve as an alternative fed to pigs.

Key words; Pig, liquid feeding, digestibility, WDG, CDS

Introduction

Wet distillers grains (WDG) and condensed distillers solubles (CDS) are co-products of the dry-grind ethanol industry. The WDG and CDS are typically blended and dried together to produce distillers dried grains with solubles (DDGS) (Klopfenstein et al., 2008)**.** Usage of DDGS in swine diets has been increasing due to its relatively low cost and increased availability from the corn ethanol industry. However, inconsistency in energy and nutrient digestibility as a result of differences in chemical composition among DDGS sources have been reported (Spiehs et al., 2002; Shurson and Alghamdi, 2008).

Most starch in grain is converted to ethanol during the fermentation process and modest amount of starch is present in DDGS. As a result, the other nutrients in DDGS are three fold compared with corn. For instance, DDGS has 35% insoluble fiber and 6% soluble fiber, which leads to lower digestibility of fiber (Stein and Shurson, 2009), and GE of DDGS compared with corn (Pedersen et al., 2007a). Additionally total content and standardized ileal digestibility (**SID**) of Lys are inconsistent among sources of corn DDGS (Goodson and Fontaine, 2004; Stein and Shurson, 2009). Lysine digestibility is most variable among all the amino acids. This could be due to overheating of DDGS during the drying process by some ethanol plants, which results in the production of Maillard products resulting in low lysine digestibility (Pahm et al., 2008). Drying wet distiller's grains is also expensive and may account for more than 40% of the energy costs incurred by the ethanol plants (Stock and Klopfenstein, 1982). For that reason using the wet products (WDG and CDS) could be economically important to the swine industry, as this will minimize the heating effect on DDGS, which will result in better lysine digestibility. Overall, alternative ingredients will take part in minimizing cost of feed for swine producers.

Liquid feeding has been reported to improve feed utilization and substantially increase growth performance, and feed digestibility (Russell et al., 1996; Geary et al., 1998; Kim et al., 2001; Brook et al., 1996; Jensen and Mikkelsen, 1998). Generally, the feed to water ratio of liquid feed can fluctuate between 1:1.5 and 1:4. Barber et al. (1991) reported that DM and energy digestibility increased linearly with the decreasing of feed to water ratio from 1:2 to 1:4. Two liquid co-products from the fuel ethanol industries which have been studied for use in swine diets are corn condensed distillers solubles (CDS) and corn steep water (de Lange et al., 2006). In a grower pig performance study, feeding fermented CDS apparently provided more beneficial lactic acid and LAB to the pigs, which improved feed and nutrient utilization, however, the digestibility of energy and protein was slightly reduced compared with pigs fed non-fermented CDS. Digestibility of fat was increased in pigs fed CDS containing diets, indicating that fat in CDS is highly digestible (Squire et al., 2004).

There is limited information on the digestibility of WDG and CDS. These ingredients and their combinations may improve digestibility of nutrients in swine. The objective of this study was to determine digestible energy (DE) and metabolizable energy (ME) and apparent ileal digestibility (AID) of amino acids in WDG and CDS for growing pigs.

Materials and Methods

The University of Minnesota Institute of Animal Care and Use Committee approved the experimental protocol (IACUC # 1104A98947).

Animal and Housing

Thirty-six crossbred barrows (Topigs × Comparts Duroc) were selected with mean initial body weight of 42 ± 1.8 kg. Pigs were individually housed in stainless metabolic housing units (MHU) (2.0 m x 0.7 m) with slatted floors, equipped with water nipples providing free access to water. The MHU were fitted with individual water meters to determine water consumption per pig. The housing units had a fine mesh screen to allow for feces to be separated from urine. Stainless steel trays were inserted under the fine mesh screen to collect urine which funneled to a plastic bucket, with 4N formalin, for collection in an environmentally controlled metabolism facility. Pigs were allowed a 10 day adaptation period before the collection period.

Ingredients, Diets and Feeding

The ethanol co-products WDG, DGGS, and CDS were obtained from Guardian Energy in Janesville, Minnesota. The analyzed nutrient composition is shown in Table 2.1.

Table 2.1 Chemical analysis of ethanol co-products (as fed basis)

Item	DDGS[1]	WDG[2]	CDS[3]
DM, %	90.00	37.00	31.50
GE, kcal/kg	4409	1968	1190
CP, %	24.20	12.60	8.10
NDF, %	27.50	16.60	0.32
ADF, %	14.10	6.40	0.23
Crude Fat, %	7.20	3.90	1.86
Lysine, %	0.89	0.41	0.35
Threonine, %	0.97	0.51	0.32
Methionine, %	0.47	0.27	0.14

[1] DDGS = distillers dried grains with solubles
[2] WDG = wet distillers grains
[3] CDS = condensed distillers solubles

A corn-soybean meal (CSBM) basal diet presented in Table 2.2 served as the control diet and was formulated to meet or exceed NRC requirement for growing pigs (NRC 2012). Four other diets were formulated based on the CSBM with the addition of 15% or 30% WDG or CDS. The last diet was based on CSBM and 15% WDG and 15% CDS**.** Celite was included in diets as an inert marker at 0.3%. Six dietary treatments were (1) CSBM basal diet A, (2) 85% basal diet B + 15% WDG, (3) 70% basal diet C + 30% WDG, (4) 85% basal diet B + 15% CDS, (5) 70% basal diet C + 30% CDS, (6) 70% basal diet C + 15% WDG + 15% CDS on a dry matter basis. The nutrient composition of the 6 experimental diets is shown in Table 2.2.

Pig BW was measured at the beginning of each feeding period and the calculated amount of feed, which was 4% of their BW, was divided into two equal daily rations and fed at 0800 h and 1600 h. The amount of feed provided to animals was recorded at each feeding time. Pigs were fed their respective diets for 14 d, with the first 10 d as an adaptation period and the last 4 d as the sample collection period. All pigs consumed all their feed throughout the entire adaptation and collection periods. Room temperature was maintained at 20 ± 1°C. Dry feed and co-product was mixed with manual concrete mixer. The amount of feed on the co-product was accounted for feed to water ratio of 40% to 60% respectively. Water meters were provided individually for each metabolism crates and water intake was measured daily before feeding.

Table 2.2 Composition of experimental basal diets (DM basis)

Ingredients	100% CSMB[1]	15% WDG[2]	30% WDG	30% CDS[3]	15% CDS	15%WDG 15%CDS
Corn	72.09	61.21	50.31	50.31	61.21	50.31
Soy bean meal	24.4	20.74	17.08	17.08	20.74	17.08
WDG	-	15.00	30.00	30.00	15.00	15.00
CDS	-	-	-	-	-	15.00
Fat	0.56	0.48	0.39	0.39	0.48	0.39
Vitamin-mineral premix	0.50	0.50	0.50	0.50	0.50	0.50
Lysine HCL	0.15	0.13	0.11	0.11	0.13	0.11
DL-Methionine	0.05	0.04	0.04	0.04	0.04	0.04
Salt	0.30	0.26	0.21	0.21	0.26	0.21
Lime stone	0.75	0.64	0.53	0.53	0.64	0.53
Dicalcium phosphate	0.90	0.77	0.63	0.63	0.77	0.63
Celite	0.30	0.26	0.21	0.21	0.26	0.21
Total	100	100	100	100	100	100

[1]CSBM = corn soybean-meal; [2]WDG = wet distillers grain; [3]CDS = condensed distillers solubles

Five diets where were made with replacement of the basal diet with 15 % of WDG or CDS, or replacement of the basal diet with 30 % of WDG, CDS, or 15% WDG +15% CDS.

The *vitamin and trace mineral premix provided the following (per kg of diet): vitamin A, 11,000 IU; vitamin D_3, 2,756 IU; vitamin E, 55 IU; vitamin B_{12}, 55µg; riboflavin, 16,000 mg; pantothenic acid, 44.1 mg; niacin, 82.7 mg; Zn, 150 mg; Fe, 175 mg; Mn, 60 mg; Cu, 17.5 mg; I, 2 mg; and Se, 0.3 mg*

Table 2.3 Analyzed chemical composition of diets (DM basis)

Nutrients (%)	100% CSBM[1]	15% WDG[2]	30% WDG	15% CDS[2]	30% CDS	15% WDG+ 15% CDS
GE (kcal/kg)	4290	4470	4382	4462	4682	4608
CP	18.89	21.62	23.75	23.13	23.25	26.10
NDF	11.31	16.63	21.33	12.76	14.12	17.16
ADF	3.52	4.06	5.11	5.38	4.59	6.27
FAT	3.31	5.86	6.22	6.81	6.02	6.57
ASH	4.60	4.40	4.39	4.23	4.49	4.19
Indispensable AA						
Arg	1.04	1.08	1.09	1.24	1.02	1.26
Hist	0.50	0.53	0.60	0.58	0.53	0.67
Ile	0.76	0.83	0.96	0.84	0.75	1.01
Leu	1.70	2.06	2.65	1.81	1.68	2.45
Lys	0.91	0.96	1.05	0.90	0.67	1.12
Met	0.30	0.35	0.44	0.35	0.29	0.44
Phe	0.91	1.02	1.23	0.98	0.87	1.21
Thr	0.70	0.78	0.91	0.80	0.73	0.97
Trp	0.22	0.23	0.24	0.24	0.22	0.25
Val	0.84	0.95	1.13	0.96	0.88	1.18
Dispensable AA						
Ala	0.98	1.23	1.59	1.10	1.04	1.49
Asp	1.83	1.82	1.93	1.92	1.60	2.04
Cys	0.26	0.31	0.39	0.34	0.31	0.42
Hyd	0.07	0.07	0.08	0.05	0.02	0.01
Tau	0.10	0.09	0.07	0.07	0.06	0.05
Glu	3.26	3.61	4.19	3.16	2.67	3.66
Gly	0.74	0.80	0.92	0.88	0.80	1.01
Pro	1.16	1.34	1.68	1.25	1.20	1.64
Ser	0.80	0.89	1.03	0.91	0.82	1.09

[1]CSBM = corn soybean-meal; [2]WDG = wet distillers grain; [3]CDS = condensed distillers solubles

Sample Collection

The experiment consisted of a 4 day of collection period, following 10 days of adaptation; feces were collected twice a day after feeding by grab sampling and urine by total collection. Urine and fecal collection trays were placed for collection of fecal and urine at the end of adaptation period. Feed samples were collected after mixing prior to feeding and stored at -20°C until further analysis. Fecal samples were collected twice daily by anal palpation of the pig to fecal output, into an aluminum pan and immediately stored at -20^{O}C. Urine was also collected with buckets placed under the tray pan containing (10 ml of 4N of formaldehyde). Weight and volume were measured, and 10% of the urine stored at -20^{O}C.

At the end of the experiment, all pigs were bled from the jugular vein to collect 10 ml blood which was then immediately centrifuged at 1500rpm for 15 min, and the separated serum was stored at -20 ^{O}C for analysis of blood urea nitrogen (BUN). Pigs were anesthetized using Telazol 1mg/kg (Tiletamine HCL and Zolezepam HCL, Form Dodge Animal Health, Inc., IA, USA) and euthanized by sodium pentobarbital 50 mg/kg (Vedco, Inc, St Joseph, MO, U.S.A). After exsanguination for sample intestinal morphology analysis, about 10 cm of ileum was excised 40 to 50 cm proximal to the ileo-cecal junction. After flushing the ileum sample with phosphate buffered saline, both ends of the ileum were tied and 10% neutral buffered formalin (NBF) was injected slowly into the ileal lumen until it maintained its uniform round shape. Ileal digesta samples were collected from the distal ileum for measurement of pH, viscosity, and amino acid digestibility. Stomach contents were also collected for measurement of pH using (pH meter ion 510 series, OAKTON EUTECK instruments, Malaysia). Weights of kidney, spleen, liver, and empty stomach, and the length of the small intestine were recorded.

Sample preparation and chemical analysis

Fecal samples were thawed and pooled for each individual animal. Fecal and feed samples were dried in a forced oven blower at 54^{O}C for 48 h and ground using a blender to a particle size of 1 mm for DM (AOAC 2000 method 939.01). The N in the feed and feces and urine samples was determined using the Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Gross energy was determined using the Bomb Calorimetry method with the IKAR-WERKE c2000 basic bomb calorimeter (IKA Werke GmbH & Co. KG, Staufen, Germany). Crude fat content of the diet was analyzed using ether extract method (AOCS Am 5-04) using ANKOM ^{HCL} hydrolysis system and ANKOM ^{XT15} Extraction system (ANKOM Technology, Macedon, NY). Samples were analyzed for NDF and ADF using a filters bag technique (ANKOM 2000 fiber analyzer, method 12 and 13, respectively; ANKOM Technology, Macedon, NY). Samples were ashed in a high temperature muffle furnace at 600 °C for 6 h. Acid insoluble ash (AIA) content of feed, and feces was determined (McCarthy et al., 1974).

Five gram samples were weighed in duplicates into digestion tubes with 100 ml of 4 N HCL along with 2 Kjeltabs (FOSS Analytical, Denmark). The samples were digested for 30 minutes at 150 °C using FOSS Tecator™ digestion system (FOSS Analytical, Denmark). The contents of the tubes were filtered through ash less filter paper (Whattman no.4) through a funnel. The filtrate was washed with boiling distilled water until the residue was free of acid. The pH of the residue was measured using litmus paper. Neutral filtrates were subjected to ashing in a muffle furnace at 600 °C for 6 h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, New Hampshire) and the ash was weighed and AIA was calculated. Digesta samples were centrifuged in Hermile z300 (Labnet international, Inc., Edison, NJ, USA) at 1,400 g for 15 minutes immediately after the collection.

The supernatant fluid was placed in a Brookfield DV-E viscometer (Brookfield Engineering Laboratories Inc., Middleboro U.S) to determine the viscosity of intestinal contents at a shear rate of 12.25 s^{-1} at 37 °C. Viscosity was measured in centipoises (cP) following the procedure of McDonald et al. (2001).

All the six diets and 36 fecal samples were analyzed for DM, GE, CP, NDF, ADF, Ash and AIA (acid insoluble ash) and all analysis were done in duplicates after drying feed and fecal samples at 54^{o}C for 48 h in an oven blower.

Ileum samples were fixed in 10% neutral buffered formalin. Tissues were processed separately; paraffin-embedded tissue blocks were made and serially sectioned at 5 microns. The slides were then stained with hematoxylin and eosin. The stained slides were scanned using an Aperio ScanScope CS digital slide scanner (Aperio Technologies, Inc. Vista, CA). The cross-section of ileum was examined histologically to determine villus height (µm) and crypt depth (µm). Approximately twenty-five linear measurements of both villus height and crypt depth were taken per pig using the Aperio image analysis algorithm framework software (Aperio Technologies, Inc. Vista, CA). These measurements were then averaged for each section respectively.

Calculation and statistical analysis

Calculations of ATTD of energy, DM, CP, EE, ADF and NDF and the DE and ME ingredients were done by difference and regression method as outlined by Bolarinwa and Adeola (2012). Apparent ileal digestibility (AID) values for AA were calculated by equation as described by Stein et al., (2007).

Equation

$$AID\ (\%) = [1 - [(AA_d/AA_f) \times (AIA_f/AIA_d)] * 100$$

where AID is the apparent ileal digestibility value of an AA (%), AA_d is AA in the ileal digesta DM g/kg, AA_f is the concentration of AA in the feed DM (g/kg), AIA_f is the AIA concentration in the feed DM (g/kg), and AIA_d concentration in the ileal digesta DM (g/kg).

Normality and homogeneity of variance of variables were determined using the UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC).Data were analyzed by ANOVA using the PROC Mixed SAS in a randomized complete block design with the individual pig as the experimental unit. The statistical model included treatment as the fixed effect and block as a random effect. When diet was a significant source of variation, treatment means were separated using the LSMEANS statement and multiple comparison was done by Tukey correction of PROC GLM. Statistical significance and tendency were considered at $P < 0.05$ and $P < 0.1$, respectively.

Result

All pigs in both stages of growth readily consumed all the feed offered during the experiment. As expected, the CP concentration in the WDG and CDS diets was greater than control basal diet, similarly for other nutrients fat, ADF and NDF (Table 2.3).

Effects of feeding WDG and CDS on apparent total tract digestibility of nutrients in diets

The apparent total tract digestibility (ATTD) of nutrients in diets is shown in Table 2.4. Pigs fed the 15% CDS and control diets had greater ($P < 0.05$) ATTD of dry matter and energy than those fed other diets. Among the 6 diets, the ATTD of energy was lowest in the 30% WDG group, whereas the 30% CDS group had the worst ATTD of nitrogen, ADF, and NDF. Inclusion of WDG and CDS led to decrease ($P < 0.05$) of ATTD of ash in comparison with the control diet. Nevertheless, pigs fed the 15% CDS and 15% CDS+15%WDG diets had higher ($P < 0.05$) ATTD of crude fat than the other 4 diets.

Effects of feeding WDG and CDS on visceral organs

The results of WDG and CDS on visceral organ weights are listed in Tables 2.5, and 2.6. Inclusion of WDG (15%WDG, 30%WDG, and, 15%WDG + 15%WDG) tended ($P < 0.1$) to increase stomach weight, but addition of 30% WDG tended ($P < 0.1$) to decrease spleen weight, when compared with the control group. During the experimental period, absolute and relative weights of liver, kidney, and length of the small intestine were not influenced ($P > 0.05$) by the dietary treatments. In addition, pH of stomach and ileal contents, viscosity of ileal digesta, and morphology of ileum (villus height, crypt depth, and their ratio) were not significantly affected ($P > 0.05$) by the diets.

Effects of feeding WDG and CDS on energy and nitrogen balance

The results of WDG and CDS on energy and nitrogen balance are presented in Table 2.7. No significant difference ($P > 0.05$) in gross energy intake was observed among the diets except that pigs fed the 30% CDS diet had lower ($P < 0.05$) gross energy intake than those fed the 15% CDS diet. Fecal energy excretion of pigs fed the 3 diets containing WDG was higher ($P < 0.05$) than animals fed the control diet, but there was no difference ($P > 0.05$) in fecal energy loss among the other diets.

Energy loss via urine did not differ ($P > 0.05$) among the treatments. Compared with the control diet, inclusion of WDG or CDS led to a decrease ($P < 0.05$) of apparent total tract digestibility of energy except for the 15% CDS diet. The ME to DE ratio was similar ($P > 0.05$) for the 6 diets, with an average of 95.4%. Pigs fed the 15% CDS and 15% WDG+15% CDS diets had greater ($P < 0.05$) nitrogen intake than animals fed the 100% CSBM and 30% CDS diets due to dietary nitrogen difference and feed intake. As for fecal excretion of nitrogen, the 30% CDS and 15% WDG+15% CDS groups were higher ($P < 0.05$) compared with the control, whereas pigs excreted similar ($P > 0.05$) amounts of nitrogen per day via urine. Apparent total tract digestibility of nitrogen for pigs fed the 30% CDS was about 10 percentage units lower than the other 5 groups ($P < 0.05$). Pigs fed the 15% CDS diet had greater ($P < 0.05$) nitrogen retention efficiency in comparison with those fed the 100% CSBM, 30% WDG, or 30% CDS diets. The 30% CDS group was the least efficient group in terms of nitrogen digestion and retention. Nevertheless, no difference ($P > 0.05$) in blood urea nitrogen was noticed.

Effects of feeding WDG and CDS on apparent ieal digestibility of amino acids in diets

Apparent ileal digestibilities of amino acids are presented in Tables 2.8. Pigs fed the 30% CDS diet had significantly lower ($P < 0.05$) apparent ileal digestibility of methionine when compared with all other groups. No significant differences ($P > 0.05$) in digestibility were noticed for other essential and nonessential amino acids among the 6 diets.

Digestible and metabolizable energy and nutrient digestibility in WDG and CDS

Digestible and metabolizable energy and nutrient digestibility in WDG and CDS are shown in Tables 2.9 and 2.10. On a dry matter basis, DE and ME for WDG are 2695 and 2322 kcal/kg, respectively, whereas DE and ME for CDS was 3244 and 3041 kcal/kg, respectively. The ATTD of energy was 61% for WDG and 73% for CDS. The AID of nitrogen was 69.5 % and 56.8% for WDG and CDS, respectively. Compared with WDG, amino acid digestibility was lower in CDS, e.g. apparent ileal digestibility of lysine (75 % vs. 58%), methionine (74% vs. 41%), threonine (75% vs. 50%), and tryptophan (78% vs. 48%).

Discussion

The apparent total tract digestibility of gross energy in most distillers' co-products is lower than corn because of the greater concentration of fiber in the co-products than in corn (Stein and Shurson, 2009). There is more information on DDGS, which is the dried form of the mixture WDG and CDS. However, there is limited report on WDG and CDS. The fiber in corn DDGS has a low digestibility in the small intestine and the fermentation in the large intestine is less than 50%, which may be the reason for the low digestibility of energy in distillers co-products (Pedersen et al., 2007a). This observation could be the reason in our current study where pigs fed 30% WDG showed lower GE digestibility compared to basal diet, which ultimately had lower ME (2562) compared to basal diet ME (3088).

The GE of the basal diet was higher than all dietary treatments except, pigs fed 15% CDS had almost same energy digestibility as the basal diet, even though pigs fed 30% CDS had lower ATTD of GE compared to basal diet. The reason for the higher digestibility of pigs fed 15% CDS diet may be due to the lower fiber and higher fat content in CDS (NRC, 2012). Fat in CDS has been reported to be highly digestible (Squire, 2004). One would expect higher ATTD of GE in the diet containing 30% CDS, but our results showed lower GE digestibility in 30% CDS diet compared to CSBM diet. Squire (2005) reported from a preliminary study in which growing pigs were fed diets containing 0, 7.5, 15.0 and 22.5% CDS that feed palatability was reduced when the dietary inclusion level exceeded 15 %. Also a high concentration of potassium (1.50%) compared to its requirement for a growing pig (0.23-0.19%) (NRC, 2012) could be a reason for the lower digestibility, because pigs fed the higher level showed some signs of diarrhea during the study period. de Lange suggested that

CDS should also be formulated for concentration of potassium based on the pig's requirement to avoid diarrhea (personal communication with de Lange).

These observations may explain the reason that pigs fed 30% CDS diet had lower energy intake compared with pigs fed the 15% CDS diet. It has been suggested that the presence of fiber could reduce the digestion of protein and fat by increasing the endogenous secretions of protein and fat associated with the increasing microbial mass (Noblet and Perez 1993). With greater fiber content in the WDG diets compared with corn–soybean meal basal diet, it was expected that more energy would be excreted in the faeces and urine, thus making the energy values greater in the basal diet than WDG diets. It was also reported that energy digestibility was negatively affected by the dietary fiber content, especially NDF (Noblet and Perez 1993). This may be the reason that in our experiment basal diet and diet with 15% CDS had greater energy digestibility compared with WDG diets and 30% CDS diet.

The DE and ME values of WDG were 2695 and 2322 kcal/kg of DM, respectively; and the DE and ME values of CDS were 3244 and 3041 kcal/kg, respectively. CDS values are lower than the reported value in NRC (2012) which is 3325 and 3198 kcal/kg respectively. One possible reason may be that oil removal after fermentation may reduce the lipid content in CDS and thus reduce the DE and ME concentrations. It has been suggested that the change of feed to water ratio results in a reduction of viscosity of the digesta and hence, allows for more interaction between digesta and digestive enzymes (Brooks, 1999). McDonald et al., (2001) increased the viscosity of pig intestinal contents with the inclusion of sodium carboxymethyl cellulose and observed villus atrophy and an increase in crypt depth in the small intestine. Villus atrophy and crypt hyperplasia are commonly related to temporary decreases in digestive and absorptive capacity of the small intestine (Pluske et al., 1997). Feeding liquid feed has been reported to improve villus / crypt ratio (van Winsen et al., 2001b; Scholten et al., 2002; Canibe and Jensen, 2003). In our experiment we did not observe significant differences in the viscosity of the ileal digesta, and no significant observation was noted on the intestinal villus and crypt depth for all the treatment diets.

The weight of metabolically active organs such as the liver, kidney and heart has been found to be positively correlated with the CP content of the diet (Kerr et al., 1995; Chen et al., 1999). When pigs are fed high-protein diets, organ weights increase as do activities of many tissue enzymes. Anugwa et al. (1989) has reported elevated relative stomach weight in response to high dietary fiber, and increased relative liver and kidney weights in response to high dietary protein. Increases in the weight of these organs can be explained by the extra metabolic load to be performed by them as a result of higher protein intake (Koong et al., 1985, Chen et al., 1999). Energy expenditure by these metabolically active tissues such as liver, gut and kidneys is much higher than energy expenditure associated with the carcass (Baldawin el al., 1980), accounting for more than 50% of the energy expenditure by the whole animal (Smith, 1970). It thus appears that high dietary fiber and protein indirectly increase the animal's maintenance requirement by causing a repartitioning of nutrients from the growth of the edible carcass to the visceral organs and consequently increasing visceral organ mass (Anugwa et al., 1989). In our experiment significant effect of fiber or CP was not observed. The reason for this could be either the concentration of fiber or CP was not high enough to induce such effect or may be due to shorter duration of our experiment.

Amino acids absorbed in excess of that amount required for protein synthesis in the body are metabolized by the liver via transamination and deamination processes (Krebs, 1942). Deamination in the liver yields ammonia which is toxic and needs to get excreted from the liver through the blood in the form of urea, which contributes to BUN (Lehninger et al., 2005). Blood urea nitrogen can be used as the indicator of quality, quantity and the biological value of protein in feed (Eggum, 1970). In our experiment we did not observe significant difference in BUN among diets.

Apparent Ileal Digestibility (AID) of AA

In the current study, AID of AA in WDG was higher compared to CDS; similar report on wheat WDG and CDS has been shown by Sondergaard et al. (2012). Also similar observation suggested by Pahm et al. (2008) that greater CP concentration in DDG than in DDGS could be a result of the lower CP concentration in distillers solubles(DS) than in DDGS in which case the CDS may have diluted the CP concentration in DDGS. It was also reported that the AA concentration of barley distillers solubles was at least 50% lower than in barley DDG (Näsi, 1985).Hence the lower AA AID in CDS could be justified simply that WDG has better source of AA than CDS (Sondergaard et al., 2012).

The AA AID of WDG and CDS ingredient results in our experiment were relatively lower with high (SEM), but comparable to published result (Table 2.11). From these studies AID of AA in DDGS was lower than dried distillers grains (DDG), which is the dry form of WDG in our study (Pahm et al., 2008). Soares et al., (2001) reported higher lysine AID digestibility of corn DDGS than the liquid condensed solubles (LCS) (which corresponds to condensed distillers solubles in our study). In another study by Soares et al. (2011), the AID and SID values of lysine and a few other AA (Table 2.11) were similar in LCS (SID lys: 63.1%) and DDGS (SID Lys: 61.5%), but the digestibility of most AA in LCS were less than the values in DDGS. In our experiment, Lysine AID of WDG and CDS were 74.78% and 57.98%, respectively. Where Lysine AID of WDG was higher than the value of lysine AID of DDGS reported by Soares et al. (2011) (AID Lysine 59%), they reported similar LCS AID of lysine (61 %) to our current finding Lysine AID 60.5%. In our experiment the effect of not exposing WDG was expressed in lysine value (AID Lys 74.78%). Pahm et al. (2008) also reported higher lysine AID value of DDG (73.4), which is similar to our current finding. Possible reasons for the higher AID value of WDG, in a similar experiment, Pahm et al. (2008) suggested the greater SID of CP and AA in DDG than in DDGS could be due to a greater AA digestibility in the whole stillage component than in the solubles. Similarly Näsi (1985) reported that the AID for CP was lower in solubles than in DDG.

Another possible reason for the higher lysine digestibility in WDG in the current experiment was that WDG are not exposed to drying which reduces lysine digestibility. The lower digestibility of lysine in DDGS is related to production units overheating the DDGS during drying, which results in the production of Maillard products resulting in low lysine digestibility (Pahm et al., 2008). In our experiment CDS was only subjected to evaporation not heat treatment comparable to production of DDGS or DDG.

Conclusion

Higher fiber content had been observed to reduce energy digestibility in diets. WDG has a high level of NDF which could be the reason for lower digestibility diets containing 15% and 30% WDG. There is potential for improvement as the combination of these ingredients in the diets resulted in relatively better digestibility of AA and overall nutrients than individual ingredients. It has been generally concluded that AA digestibility is higher in WGD than CDS.

Lysine digestibility was higher as expected for WDG because it was not exposed to drying. Drying reduces lysine digestibility. CDS is a good source of fat, hence diets containing considerable amount of CDS showed higher energy digestibility. Higher level of CDS tends to affect digestibility of diets leading to lower digestibility of treatment diets containing 30% CDS. As previously mentioned in other studies, higher levels of CDS reduce performance. Care should be taken when formulating CDS. More research is required to explore the benefit of these ingredients as they could take part in reducing cost of feed.

Table 2.4 Estimate of ATTD of diets containing ethanol co-products

Item	100% CSBM[1]	15% WDG[2]	30% WDG	15% CDS[3]	30% CDS	15% WDG+ 15% CDS	SEM	$P_{(value)}$
DM	75.99[a]	67.77[b]	64.18[b]	73.44[a]	61.47[b]	67.04[b]	1.5	0.0001
GE	74.85 [a]	65.95[b]	61.6[c]	74.87[a]	64.83[b]	68.46[b]	1.4	0.0001
CP	73.48 [a]	71.17[a]	72.71[a]	73.21[a]	58.19[b]	72.83[a]	1.4	0.0001
ADF	63.95 [a]	66.90[ac]	67.58[ac]	76.38[c]	46.73[b]	71.57[ac]	2.2	0.0001
NDF	49.22 [a]	42.58[a]	36.09[a]	54.29[a]	21.88[b]	41.22[a]	2.5	0.0001
ASH	72.22 [a]	59.42[b]	53.46[b]	62.07[ab]	51.99[b]	54.52[b]	2.8	0.0002
FAT	23.45[b]	24.18[b]	20.95[b]	50.46[a]	35.59[b]	43.70[a]	1.0	0.0001

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles

Table 2.5 Effect of dietary treatments on ratio of final BW to organ weight and intestinal length

Item	100% CSBM[1]	15% WDG[2]	30% WDG	30% CDS[3]	15% CDS	15% WDG+ 15% CDS	SEM	p (value)
Final body wt. kg	58.79	59.02	58.79	57.96	57.42	60	2.33	0.98
Stomach wt. (g/kg)	6.75	7.76	7.58	6.9	7.05	7.37	0.26	0.07
Liver wt. (g/kg)	20.8	24.13	23.03	24.61	25.56	23.67	2.48	0.82
Kidney wt. (g/kg)	4.95	4.77	4.42	5.32	5.23	4.82	0.24	0.13
Spleen wt. (g/kg)	3.55	3.17	1.83	3.86	2.68	2.79	0.48	0.08
Intestinal length (m/kg)	0.28	0.27	0.26	0.27	0.26	0.27	0.01	0.81

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles
*Values are ratio of organ weight to final BW

Table 2.6 Effect of treatment diets on pH, viscosity and morphology of GIT components

Item	100% CSBM[1]	15% WDG[2]	30% WDG	15% CDS[3]	30% CDS	15% WDG+ 15% CDS	SEM	$P_{(value)}$
Stomach pH	3.41	3.81	3.20	3.90	3.10	3.52	0.69	0.91
Ileal pH	6.53	6.61	6.80	6.60	6.69	6.63	0.11	0.61
Ileal viscosity	2.28	2.26	2.55	2.58	2.43	2.27	0.28	0.92
Villus height (um)	625.3	594.9	581.8	583.3	626.7	619.3	39.6	0.92
Crypt depth (um)	189.1	214.8	205.8	187.0	193.6	205.6	10.3	0.36
Villus: Crypt	3.36	2.78	2.85	3.10	3.24	3.02	0.16	0.13

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles

Table 2.7 Energy and nitrogen balance of experimental diet (100% DM basis)

Item	100% CSBM[1]	15% WDG[2]	30% WDG	15% CDS[3]	30% CDS	15% WDG+ 15% CDS	SEM	p value
Energy intake (Kcal)	8612^{a}	9160^{a}	8607^{a}	10238^{a}	7752^{b}	9653^{a}	432.9	0.007
Energy in feces (Kcal)	2175^{b}	3104^{a}	3302^{a}	2566^{ab}	2728^{ab}	3037^{a}	179.2	0.002
Energy in urine (Kcal)	41.4	71.93	65.07	70.59	71.27	6870	10.4	0.461
DE of the diet (kcal/kg)	3212^{ab}	2948b^{c}	2699^{c}	3341^{a}	3035^{b}	3155^{ab}	64.6	0.001
ME of the diet (kcal/kg)	3088^{ab}	2827b^{c}	2562^{c}	3199a	2847^{bc}	3008^{ab}	70.7	0.001
ME/DE	96.12	95.86	94.9	95.76	93.77	96.12	0.62	0.122
ATTD of GE (%)	74.85^{a}	65.95^{bc}	61.60^{c}	74.87^{a}	64.83^{bc}	68.46^{b}	1.44	0.000
N intake (g)	60.66^{c}	70.89^{bc}	74.65^{abc}	84.94^{ab}	61.60^{c}	87.47^{a}	3.45	0.001
N feces (g)	16.19^{b}	20.45^{ab}	20.39^{ab}	22.67^{ab}	25.85^{a}	23.77^{a}	1.54	0.004
N urine (g)	34.3	23.44	35.39	21.44	23.51	31.58	4.18	0.089
N digested (g)	44.47^{bc}	50.44^{b}	54.25^{ab}	62.27^{a}	35.76^{bc}	63.70^{a}	2.56	0.001
ATTD of N (%)	73.48^{a}	71.17^{a}	72.71^{a}	73.21^{a}	58.19^{b}	72.83	1.36	0.001
N retention	40.37^{b}	53.44^{ab}	41.52^{b}	65.02^{a}	33.64^{b}	50.41^{ab}	4.87	0.002
[4]ADWI, (l)	1.68	1.88	2.51	2.79	1.023	3.65	2.62	0.615
[5]BUN, (mg/dL)	11.8	12.77	12.75	12.72	13.43	14.42	1.48	0.080

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles
[4]ADWI= average daily water intake
[5]BUN = blood urea nitrogen

Table 2.8 Apparent ileal digestibility (%) of AA in the dietary treatments

Item	100% CSBM[1]	15% WDG[2]	30% WDG	15% CDS[3]	30% CDS	15% WDG+ 15% CDS	SEM	$P_{(Value)}$
Indispensable AA								
Arg	71.22	67.13	64.93	73.02	53.82	71.75	5.52	0.17
Hist	65.03	62.16	66.22	53.87	55.56	64.04	7.59	0.75
Ile	61.47	56.54	68.36	61.29	49.99	64.24	6.18	0.48
Leu	57.84	63.75	70.92	58.31	47.80	65.37	5.54	0.10
Lys	61.37	64.22	63.41	58.55	53.65	62.57	7.82	0.83
Met	67.29[a]	66.31[a]	72.60 [a]	63.6[a]	45.9[b]	68.44[a]	5.20	0.03
Phe	61.16	58.57	64.45	61.01	46.34	64.86	5.40	0.24
Thr	52.28	56.18	66.57	56.19	49.67	58.32	6.53	0.49
Trp	60.84	67.23	59.46	61.02	50.53	59.18	6.32	0.79
Val	51.91	61.01	53.72	53.51	38.49	58.06	8.31	0.60
Dispensable AA								
Ala	51.42	56.61	60.28	52.27	40.49	58.90	6.44	0.32
Asp	62.65	52.47	53.71	59.59	54.68	59.16	7.70	0.92
Cys	56.17	52.69	62.88	56.33	44.98	56.01	4.64	0.60
Glu	65.70	64.90	65.17	65.56	45.16	62.30	6.42	0.28
Gly	32.40	29.87	45.48	43.78	35.76	42.60	2.11	0.08
Pro	59.67	56.57	65.79	57.25	47.68	62.01	6.74	0.57
Ser	57.57	62.22	58.41	57.27	42.41	60.35	6.65	0.50

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles

Table 2.9 Apparent ileal digestibility (%) of AA in ingredients of WDG and CDS (Means±SEM)

Item	WDG[1]	CDS[2]
Indispensable AA		
Arg	75.12 ±16	70.88 ±13.2
Hist	78.56±11.8	54.98±13.6
Ile	73.77±13.7	53.39±17.5
Leu	84.81±10.74	39.67±12.2
Lys	74.78± 15.4	57.98 ±13.8
Met	74.25±9.28	40.69±19.92
Phe	80.53±14.92	62.92±16.01
Thr	75.43±10.74	49.92±11.37
Trp	78.05±21.76	48.37±19.23
Val	57.48±17.53	38.78±22.59
Dispensable AA		
Ala	68.65±12.56	46.13±6.76
Asp	56.22±3.49	49.12±9.99
Cys	54.74±27.88	28.66±19.45
Glu	77.80±15.66	44.56±11.75
Gly	61.71±17.34	50.5±7.43
Pro	67.71±13.75	44.53±6.42
Ser	69.08±18.01	41.78±8.89

[1]WDG = wet distillers grain
[2]CDS = condensed distillers solubles

Table 2.10 DE, ME, and ATTD energy digestibility in WDG and CDS

Item	WDG[1]	CDS[2]
DE (kcal/kg)	2695	3244
ME (kcal/kg)	2322	3041
ATTD GE (%)	61	73

[1]WDG = wet distillers grain
[2]CDS = condensed distillers solubles

Table 2.11 Digestibility of CP, amino acids AID of WDG and CDS from the present study and other comparable ethanol co-products from wheat and corn

	Corn WDG[1]	Corn CDS[2]	**Wheat** CDS	**Wheat** CDS	**Corn** DDGS[3]	**Corn** LCS[4]	**Corn** DDGS	**Corn** DDG[5]
Item	present study	present study	Søndergaard et al., 2012	Søndergaard et al., 2012	Soares et al., 2011	Soares et al., 2011	Pahm et al., 2008	Pahm et al., 2008
CP	69.5	56.8	75	63.4	55.2	41.7	61.3	66.7
Indispensable AA								
Arg	75.12	70.88	82	75.2	76.5	65	71.9	75
Hist	78.56	54.98	79.9	74.5	74.4	71.5	76.3	81.3
Ile	73.77	53.39	72.4	59.1	75	58.7	73.8	80.4
Leu	84.81	39.67	78.8	71.6	81.8	57.8	82.1	84.4
Lys	74.78	57.98	67.5	64.6	59.8	61	59	73.4
Met	74.25	40.69	79	68.6	82.3	40.1	80.7	87.5
Phe	80.53	62.92	84.5	76.9	80.1	60.4	77.9	83.4
Thr	75.43	49.92	63.8	46.7	64.2	40.8	65.3	71.4
Trp	78.05	48.37						
Val	57.48	38.78	73.7	60.9	71.9	58.8	73	77.5
Dispensable AA								
Ala	68.65	46.13	70.5	65.1	73.2	52.8	74.3	78.1
Asp	56.22	49.12	56.9	44.1	62.5	36.5	62.9	68.6
Cys	54.74	28.66	73.7	58	68	47.5	71.1	77.2
Glu	77.8	44.56	95	92.7	76.3	47	79.1	84.6
Gly	61.71	50.5	67.4	54.4	31.3	8.2	38.7	40
Pro	67.71	44.53	86.4	73.5	5.6	-94	6.8	11.5
Ser	69.08	41.78	74.8	45.8	72.7	50.6	71.6	76.2

WDG[1] = Wet distillers soluble, CDS[2] = Condensed distillers solubles, DDGS[3] = Dried distillers grain and solubles , LCS[4] = liquid condensed solubles, DDG[5] = Dried distillers grain

Chapter 3

Effects of corn-ethanol co-products in a liquid feeding system on growth performance and carcass characteristics of wean to finish Pigs

Summary

The objective of the current study was to determine the ratio of wet distiller's grains (WDG) to condensed distiller's solubles (CDS) on the performance of wean to finish pigs fed via a computer-based automatic liquid feeding system. Two hundred and eighty early weaned pigs (18 ± 3 d old; Topigs 20 X Compart Duroc were blocked by initial BW (6.47 ± 1.4 kg) and allotted randomly to 1 of 4 dietary treatments (10 pigs/pen and 7 pens/treatment). The dietary treatments were: 1) corn-soybean meal basal diet (CSBM) with 20% dried distiller's grain with solubles (DDGS); 2) CSBM with 20% WDG; 3) CSBM with 17% WDG + 3% CDS; and 4) CSBM with 14% WDG + 6% CDS. The experiment began 2 weeks post-weaning to finishing (126 days on trial) using a 5-phase feeding program. The overall ADG was 0.912, 0.934, 0.957, and 0.937 kg/d, ADFI on a dry matter basis 2.47, 2.2, 2.26, and 2.24 kg/d, and gain to feed ratio 0.33, 0.37, 0.38, and 0.37, for treatments 1 to 4, respectively. Overall ADG was higher (P = 0.05) in the 17%WDG + 3%CDS compared with the 20%DDGS, but there was no (P > 0.05) difference in ADG among 20%DDGS, 20%WDG and 14% WDG plus 6% CDS treatments. Additionally, WDG, 17%WDG + 3%CDS and 14% WDG + 6% CDS had lower (P = 0.001) overall ADFI than DDGS fed pigs. Overall G: F of DDGS- fed pigs was less (P = 0.001) than pigs fed the other 3 dietary treatments. Final BW of 17%WDG + 3%CDS fed pigs was greater (P = 0.02) than pigs fed DDGS. Dietary treatments did not influence (P > 0.05) BUN concentration and carcass characteristics. Thus, WDG and the combinations of WDG and CDS had a beneficial effect on growth performance compared with DDGS.

Key words; Pig, liquid feeding, automated, growth performance,

Introduction

The form of feed is a very important factor immediately after weaning as piglets are abruptly moved away from the sows and a predominantly liquid (sow's milk) form of diet. Liquid feeding had been shown to alleviate nutritional stress level that usually occurs during transition from sow's milk to dry feed (Plumed-Ferrer et al., 2005). Research studies have shown that liquid feeding can improve feed utilization and subsequent growth performance and feed digestibility (Russell et al., 1996; Geary et al., 1998; Kim et al., 2001; Brook et al., 1996; Jensen and Mikkelsen, 1998). The gut lumen of pigs is the site of absorption of nutrients, so a temporary starvation could cost a piglet reduction in villus height which affects absorption capacity in the gut (Pluske et al., 1996ab). Likewise, a diet that is palatable and acceptable by the newly weaned pig will guarantee adequate supply of nutrients to the brush border of the small intestine.

However, the majority of these benefits have been documented in European research studies where pigs are fed barley and wheat based diets (de Lange, 2012). Research studies with liquid feed co-products, mostly come from food and dairy industries, have reported variable results. For example, Russell et al. (1996) and Kim et al. (2001) reported that liquid feeding improved growth performance compared with dry feeding. In contrast, Lawlor et al. (2002), found no benefits of liquid feeding on the growth performance of newly weaned piglets.

Liquid feeding of newly weaned pigs using corn-based ethanol co-products has not been adequately studied. In various studies conducted at the University of Guelph, the feeding values of CDS, CSW and whey permeate have been broadly evaluated. They reported that use of CDS and CSW had less effect on growth performance and carcass quality when used at 15% or less diet DM content, while whey permeate can increase growth performance at 20% inclusion of DM content in nursery diets (de Lange et al., 2006). Additionally WDG and CDS have been combined by ethanol industries with the aim of having a dry high quality ingredient. However, mixing of inconsistent ratios of WDG and CDS leads to variation in quality from batch to batch which changes the feed value, and creates apprehensions among nutritionists and directly impacts the economics of ethanol production (Kingsly et al., 2010; Singh et al., 2001). The current project evaluated the effect of combinations of WDG and CDS on the performance of wean to finish pigs to determine feeding values for these corn ethanol by-products.

Therefore, the objectives of this project were to compare the performance and carcass characteristics in wean-to-finish pigs fed 20% DM from distillers' dried grains with solubles (DDGS) to that of pigs fed a combination of WDG and CDS and also determine the optimal ratio of WDG to CDS.

Materials and Methods

Experimental design

The experimental protocol was reviewed and approved by the University of Minnesota Institutional Animal Care and Use Committee (IACUC # 1104A98947). The trial was conducted in the wean-to-finish facility at the University of Minnesota's Southern Research and Outreach Center, Waseca, MN.

A total of 280 pigs (Topigs 20 X Compart Duroc) borrow and gilts were weaned into the Southern Research and Outreach Center Swine Research Unit (Waseca, MN), in environmentally controlled rooms. Piglets were weaned at 18 ± 3 d of age at an average body weight of 6.47 ± 1.4 kg. Pigs were identified by ear-tags at weaning, blocked by body weight, and randomly assigned to 4 dietary treatments with 7 pens per treatment and 10 pigs (5 barrows and 5 gilts) per pen using completely randomized block design. The four dietary treatments were: corn-soybean meal basal diet (CSBM) with 20% DDGS, CSBM with 20% WDG, CSBM with 17% WDG + 3% CDS and CSBM with 14% WDG + 6% CDS Pigs were allowed to adapt to a common liquid diet for two weeks before starting the experiment. Pigs were fed according to a 5 phase feeding program (Table 3.1). Within each phase the experimental diets were formulated to meet or exceed nutrients requirements for wean to finish pigs (NRC, 2012).) All pens had concrete slats, a single liquid feeding trough with sensor on the side of the pen, and a water bowl with free access to water. Pens provide 0.74 sq. m. per pig at a stocking density of 10 pigs per pen.

In the current experiment liquid feeding system; Hydrojet computerized liquid feeding system (Big Dutchman, Germany) was used as a means to feed pigs. The system is controlled with computer software, so feeding system was managed automatically. Once the feeding amount and feeding times is programed based on feed curves relating to pigs weight, feeding was automatically managed based on sensor information of individual trough and data on amount feed disappearance were recorded automatically. The dry portion, the ethanol co-products and water was mixed in a central unit mixer of the system. Once the system sends information on the amount of ingredients to prepare feed for specific treatment, feed is delivered to mixing tank via a computer controlled pipes. After mixing for few min feed is pumped via high pressure air through the pipes to individual trough based on the need of the number of pigs in a pen corresponding to their feeding curves. The computer control the feed preparation, feed mixing for individual pens and monitor weight changes of the mixing tank. The ratio of water to feed was set in the program and feed was delivered and prepared for each treatment after agitation using high pressure air pump. After every feeding the pipes were rinsed with high pressure water to clear any remaining feeds prior to preparation for another batch. Feed allowance was increased based on the feed curve that was related to estimated body weight. Pigs were fed 4-12 times a day using the computerized liquid feeding system. For the first 2 phases pigs were fed the liquid diet of their respective treatment at 30% DM in the final mixture, but were offered 40% DM after phase two to maximize feed intake. Phases were transitioned by the computer controlled program. .

Sample and Data collection

During the experimental period of 126 days, feed samples were collected during each dietary phases for analysis. Pig's body weights and water intake were recorded at the beginning and end of each diet dietary phase and feed disappearance was recorded on a daily basis by the system. Performance parameters were determined; average daily gain (ADG), average daily feed intake (ADFI), and feed conversion efficiency (G: F). Blood samples were taken on day 98 from one pig per pen and centrifuged at 1500 rpm for 15 min to get the serum for BUN analysis. Animals were observed daily for signs of morbidity and mortality, feed and water outages, and environmental temperature. Daily minimum and maximum temperatures were recorded each morning.

Carcass evaluation

At the end of phase 5, pigs were shipped to a commercial abattoir, Tyson Foods, Inc. where data on standard carcass measurements (dressing percentage, fat depth, loin depth, and lean percentage) were collected.

Chemical analysis

All diet~~s~~ samples were analyzed for DM, gross energy (GE), CP, crude fat by acid hydrolysis (CF), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ash content. All the analyses were done in duplicate. Feed samples were dried at 54 °C for 48h h in a forced oven. Dry matter was analyzed by AOAC (2000) method 939.01. The CP was determined using Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Gross energy was determined by bomb calorimetry with a IKA WERKE c2000 basic bomb calorimeter (IKA Werke GmbH & Co. KG, Staufen, Germany). Crude fat was analyzed by the ether extract method (AOCS, 2009 method Am 5-04) using ANKOM XT15 extraction system (ANKOM Technology, Macedon, NY). Samples were analyzed for NDF and ADF using a filter bag technique (ANKOM2000 fiber analyzer, method 12 and 13, respectively; ANKOM Technology, Macedon, and NY). The total ash content of the samples was weighed before and after ashing in a high temperature muffle furnace at 600 °C for 6h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, New Hampshire).

Blood Urea Nitrogen

Blood urea nitrogen was measured with the Stanbio Urea Nitrogen kit (BUN) Liquid- UVR (Stanbio laboratory, Boerne, Texas) using the method described by Sampson et al. (1980). A Thermo scientific Genesys 20 spectrophotometer was the used to read the absorbance. The spectrophotometer was calibrated at 340 nm with distilled water at zero absorbance. Absorbance was recorded in the spectrophotometer after 30 s and at exactly 60 s after first reading. Changes in the absorbance were recorded at these times to calculate the BUN.

Calculations

Growth performance parameters, average daily gain (ADG), average daily feed intake (ADFI) and feed efficiency (G: F = ADG: ADFI) were calculated per pen on a weekly basis.

Serum blood urea nitrogen was calculated by using the equation:-

Serum BUN (mg/dL) = (ΔA serum / ΔA standard)*30

Where ΔA serum is the change/decrease in the absorbance of the serum sample, ΔA standard is the change/decrease in the absorbance of the standard and 30 was the concentration of the standard (mg/dL) used.

Statistical analysis

Pen was used as experimental unit. Data were subjected to analysis of variance (ANOVA) based on the general lineal model of procedure of SAS, version 9.2 (SAS Institute Inc., Cary, NC). Treatment and block were considered as a source of variation. Initial body weight was used as a covariant for growth performance data. Least squares means were separated by the PDIFF and Tukey's test option. Statistical significance was measured at the 0.05 level.

Result

The effect of co-products on performance of pigs is shown in Table 3.4. In phase 1 (d 0-14) there was no difference ($P > 0.05$) on ADFI among the dietary treatments. However, pigs fed 17%WDG + 3%CDS and 14%WDG + 6%CDS had significant higher ($P < 0.05$) ADG compared with pigs fed the 20%DDGS diet. Feed efficiency of the pigs fed diets containing WDG and/or CDS was improved ($P < 0.05$) by about 15% in comparison with the control group.

In the second phase (d 14-35) pigs from the 17%WDG + 3%CDS group gained more ($P < 0.05$) than those from the control and 20%WDG group. No difference ($P > 0.05$) in ADFI and feed efficiency was observed among the 4 groups. During the third phase (d 35-56) dry matter intake of pigs in the control group as improved ($P < 0.05$) by approximately 16%, but feed efficiency was 7-14% more in the 3 groups compared to control diet. No difference ($P > 0.05$) in ADG was noticed among the treatments

During the fourth phase (d 56-98) pigs in the control group ingested around 15% more ($P < 0.05$) dry matter, but had similar ($P > 0.05$) ADG and G:F in comparison with the other 3 groups. In the fifth phase (d 98-126), pigs in the control group ate more and had worse feed efficiency than the remaining 3 groups ($P < 0.05$). In addition, pigs fed the 20%WDG diet and the 17%WDG + 3%CDS diet had higher ($P < 0.05$) ADG than animals fed the other 2 diets.

Over the whole experimental period, pigs fed 17%WDG + 3%CDS had higher ($P \leq 0.05$) ADG than pigs fed the control diet (0.96 vs. 0.91 kg/d). Furthermore, about 10% reduction in dry matter intake and 15% improvement in feed efficiency for pigs fed diets containing WDG and/or CDS were noticed ($P < 0.05$) when compared with the control group.

Effect of liquid feeding on blood urea nitrogen, carcass characteristics and water intake

The carcass characteristics and blood urea nitrogen are presented in Table 3.5, and water intake table 3.6. No difference ($P > 0.05$) was observed for dressing percentage, back fat depth, and lean percentage. Also no difference was observed ($P < 0.05$) on blood urea nitrogen and water intake among the 4 dietary treatments.

Discussion

There is a paucity of information on liquid feeding using corn-ethanol plant co-products (WDG and CDS) in swine diets. The aim of this experiment was to determine the effect of incorporating WDG and CDS in a liquid feeding system for wean to finish pigs on growth performance and carcass characteristics and to determine the ideal ratio of WDG and CDS based on the performance results.

Most reported studies compared liquid feed to dry feed and indicated improvements in growth performance, dry matter intake and nutrient utilization by liquid feed (Kim, 2001; Scholten et al., 1999; Brook, 2001). An increase in ADFI is associated with an increase in average daily gain. For instance, Jensen and Mikkelsen (1998), based on a review of several studies concluded that liquid feeding of newly weaned pigs resulted in 12% increase in ADG in comparison to dry feeding. In our experiment we did not compare dry and liquid feeding and all diets were fed in liquid form. We did compare the CDS and WDG with DDGS at different combinations. Pigs fed the diet containing 17% WDG and 3% CDS had the highest ADG during the wean-to-finish period (Table 3.4). Improving feed intake during the post-weaning period is very important for encouraging development of the small intestine and subsequent growth performance and in maintaining gut integrity and thereby preventing the "growth lag" associated with weaning (Deprez et al., 1987; Pluske et al., 1997). Improved ADFI as reported by Jensen and Mikkelsen (1998) was correlated with higher weight gain. In our experiment we saw pigs on control 20% DDGS had significantly higher ADFI from Phase 3-5 but this was not reflected on ADG (table 3.4).

In the present study, better feed efficiency and lower ADFI for the 3 test diets containing WDG and CDS may be mainly due to the fact that calculated ME, expressed on a dry matter basis, of the 3 diets was higher compared with energy level in the control diet. Analyzed GE was lower for basal diet (Table 3.2) compared to other diets though showed lower efficiency, this could also be a possible reason for higher intake of pigs fed basal diet compared to the other 3 diets. Similarly calculated ME was lower for basal diet compared to test diets (Table 3.3).

Another possible reason could be wastage of feed by pigs fed on DDGS based basal diet, because only feed disappearance was measured not wastage. Feed disappearance was measured by the system automatically which is engineered to make sure most of the feed supplied would be consumed before another batch of feed is delivered to the trough with information from sensors detecting amount of feed left in trough. Improved feeder design may help decrease feed wastage. Partridge et al. (1992) found that feed conversion was unaffected by liquid feeding when an experimental automated liquid feeder that dispensed feed and water at a ratio of 1:1 was used. Brooks et al. (1996) also found that feed conversion of pigs offered liquid feed was similar to that found for pigs offered dry pelleted feed when the feeder design was improved. In our experiment the liquid to feed ratio was kept at 2.3: 1 for the first two phases then later decreased to 1.5: 1 to increase feed intake.

The benefits of liquid feeding pigs have long been reported with, wheat and barley based diets were used (Brooks et al., 2001). Even though other studies show no advantage of growth performance of newly weaned pigs when fed liquid diet (Pedersen et al., 2005; de Lange et al., 2006), it is possible that there are greater benefits of liquid feeding based on wheat and barley diets than corn based diets. Compared with ground wheat and barley, ground corn has rather distinctive physical and nutritional features, such as high bulk density, rapid settling when suspended in water, low water binding capacity, high starch and low fiber, and no endogenous phytase activity (de Lange, 2012). In terms of nutrient digestibility and digestible energy content, wheat and barley have lower nutritional value than corn (NRC, 2012). It is therefore, possible that the feeding value could be improved for liquid feed soaked for short periods before feeding, especially with fibrous and lower digestibility ingredients (de Lange, 2012). In our experiment we did not apply any soaking technique to improve nutritional value. Pigs were fed fresh co-products from the plant and preservatives were added to prevent molding.

In a similar experiment done at the University of Minnesota (Baidoo et al., 2014), where co-products were fed in liquid form, 30% DDGS as a control and combination of WDG and CDS where studied for a wean to finish growth performance study. The result showed no performance benefits for pigs fed on the control diet versus pigs fed on the wet/liquid co-products. But pigs fed on 25% WDG plus 5% CDS showed 5% increase in efficiency compare to control 30% DDGS. This is similar to our current findings where pigs fed on diet 3 (17% WDG + 3% CDS) had higher efficiency compared to pigs fed on control diet 1(20% DDGS).

Conclusion

In conclusion, our results indicate that 17%WDG + 3%CDS is the best combination among the 4 treatments tested under our experimental conditions. Pigs fed on test diets had better overall ADG compared to pigs fed on control diets 20%DDGS in all phases. Liquid co-products from ethanol industries could be cheaper alternatives to dry forms like DDGS, which could reduce cost of feed for swine producers. Also for ethanol plant industries, it reduces the cost of energy spent on drying to make DDGS. Feed intake was higher for pigs fed on the control diet (20% DDGS) which needs further investigation because we did not observe the increase in feed intake being reflected in conversion efficiency. More research is required to achieve thorough explanation. Application of liquid feeding has considerable appeal as it allows the usage of cheap co-products.

From our study we showed that ethanol co-products; WDG and CDS, in wet form could be viable for both the swine producer and ethanol plant industries as it reduces energy expenditure for drying. Automated liquid feed is a new technology in North America especially in US, one higher potential for liquid co-products production from ethanol industry in the Midwest, where most of ethanol industries are located,, this opportunity needs to be explored for the betterment of swine producers. Automated liquid feeding systems have long been used for piglets after weaning which has a positive benefit during transition after weaning and ultimately health and wellbeing of the animal. Using liquid feed also benefits the environment by utilizing co-products that will otherwise, could have been an environmental concern if not utilized.

Table 3.1 Feed ingredients composition of the four treatment diets

	Phase 1				Phase 2				Phase 3				Phase 4				Phase 5			
Ingredients, %	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Corn	43.8	35.5	35.6	35.7	56.4	44.2	41.4	41.4	59.8	47.0	47.6	47.6	59.7	42.9	42.9	42.9	59.7	47.6	47.6	47.6
cDDGS	20	-	-	-	20	-	-	-	20.0	-	-	-	20.0	-	-	-	20.0	-	-	-
Liquid CDS	-	-	3	6	-	-	3	6	-	-	3.0	6.0			3.0	6.0		-	3.0	6.0
Wet Distillers Grains	-	20	17	14	-	20	17	14	-	20.0	17.0	14.0		20.0	17.0	14.0		20.0	17.0	14.0
SDPP	1.5	1.5	1.5	1.5					-	-	-	-		-	-	-		-	-	-
Whey Powder	8	8	8	8	-	-	-	-	-	-	-	-		-	-	-		-	-	-
SBM, (47.5% CP)	18	24	24	24	18	26	28.5	28.5	16.0	24.0	24.0	24.0	16.0	27.1	27.1	27.1	16.0	24.0	24.0	24.0
Choice White Grease	2	4	4	4	0.5	4.5	5	5	1.0	5.0	5.0	5.0	1.0	5.6	5.6	5.6	1.0	5.0	5.0	5.0
Fishmeal	3	3	3	3	1	1	1	1	-	-	-	-		-	-	-		-	-	-
Limestone	0.9	0.7	0.7	0.7	1.1	0.8	0.9	0.9	1.1	1.0	0.8	0.8	1.1	0.9	0.9	0.9	1.1	0.8	0.8	0.8
Dicalcium phosphate	0.2	0.7	0.73	0.6	0.7	1.2	1.15	1.15	0.7	1.5	1.2	1.2	0.7	1.9	1.9	1.9	0.7	1.2	1.2	1.2
Lysine HCL	0.6	0.5	0.5	0.5	0.4	0.4	0.2	0.2	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
DL-Methionine	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2
L-Threonine	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
L-Tryptophan	0.03	0.02	0.02	0.02	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salt	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Nursery Vit-TM mix	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5			-	-		-	-	-		-	-	-
Vit-TM mix			-	-					0.3	0.4	0.2	0.2	0.5	0.3	0.3	0.3	0.5	0.2	0.2	0.2
Zinc Oxide	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	-	-	-	-		-	-	-		-	-	-
Mecadox	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	-	-	-	-		-	-	-		-	-	-
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

1= 20% DDGS, 2= 20% WDG, 3= 17%WDG + 3%CDS, 4=14%WDG + 6%CDSThe *vitamin and trace mineral premix provided the following (per kg of diet): vitamin A, 11,000 IU; vitamin* D_3*, 2,756 IU; vitamin E, 55 IU; vitamin* B_{12}*, 55µg; riboflavin, 16,000 mg; pantothenic acid, 44.1 mg; niacin, 82.7 mg; Zn, 150 mg; Fe, 175 mg; Mn, 60 mg; Cu, 17.5 mg; I, 2 mg; and Se, 0.3 mg*.

Table 3.2 Analyzed composition of dietary treatments (DM basis)

Dietary treatments										
	20%DDGs					20% WDG				
Phases	1	2	3	4	5	1	2	3	4	5
GE	4013	3980	3966	4001	3975	4219	4209	4241	4206	4135
CP	20.83	19.61	17.40	17.80	19.22	23.74	21.44	18.84	19.57	19.59
Fat	5.12	5.39	4.17	5.89	6.93	7.55	7.88	9.18	8.04	6.85
ADF	5.14	4.76	4.92	4.33	4.22	4.87	5.55	6.05	5.74	5.72
NDF	10.41	12.03	14.56	13.79	12.80	8.81	10.44	13.08	10.12	9.42
Ash	4.40	4.70	4.36	4.49	5.03	4.28	4.64	4.17	4.38	4.98
Dietary treatments										
	17%WDG +3% CDS					14%WDG+6%CDS				
Phases	1	2	3	4	5	1	2	3	4	5
GE	4179	4168	4200	4165	4095	4138	4127	4160	4125	4054
CP	23.54	21.24	18.64	19.38	19.40	23.35	21.05	18.45	19.18	19.20
Fat	7.41	7.74	9.05	7.91	6.71	7.28	7.61	8.91	7.77	6.57
Ash	4.52	4.88	4.41	4.62	5.22	4.76	5.12	4.65	4.86	5.46
ADF	4.42	5.11	5.61	5.29	5.28	3.98	4.66	5.16	4.85	4.83
NDF	7.62	9.25	11.89	8.94	8.23	6.43	8.07	10.70	7.75	7.04

1= 20% DDGS, 2= 20% WDG, 3= 17%WDG + 3%CDS, 4=14%WDG + 6%CDS

Table 3.3 calculated composition of dietary treatments (DM basis)

Calculated analysis of treatments										
	20%DDGs					20% WDG				
Phases	1	2	3	4	5	1	2	3	4	5
ME	3209	3209	3262	3256	3255	3360	3370	3404	3423	3425
CP	18.8	18.8	17.5	17.5	17.5	23.5	22.0	20.7	21.8	20.7
ADF	5.6	5.6	5.6	5.6	5.6	6.0	6.4	6.3	6.4	6.4
NDF	11.2	11.2	11.3	11.3	11.3	13.3	14.1	14.1	14.0	14.2

	17%WDG+3%CDS					14% WDG+6%WDG				
Phases	1	2	3	4	5	1	2	3	4	5
ME	3365.3	3409.6	3429.1	3427.7	3429.2	3373.1	3409.6	3432.6	3431.4	3433.0
CP	23.3	22.6	20.5	21.6	20.5	23.1	22.6	20.3	21.4	20.3
ADF	5.5	5.5	5.9	5.9	5.9	5.0	5.5	5.4	5.4	5.4
NDF	12.0	11.4	12.8	12.7	12.8	10.7	11.4	11.5	11.4	11.5

1= 20% DDGS, 2= 20% WDG, 3= 17%WDG + 3%CDS, 4=14%WDG + 6%CDS

Table 3.4 Effects of dietary treatments on pig growth performance

Growing phase	Dietary treatment (20 % DDGS)	20 % WDG	17 % WDG + 3 % CDS	14 % WDG + 6 % CDS	SEM	*P* Value
			Body weight (BW), kg			
Initial BW	9.95	9.73	9.81	9.94	6.52	0.68
Day 14	15.75	15.85	16.39	16.47	6.68	0.12
Day 35	30.38 [a]	30.51 [a]	32.07 [b]	31.57 [b]	1.45	0.03
Day 56	51.73	51.48	52.99	52.19	2.15	0.58
Day 98	100	97.04	99.94	99.63	2.59	0.17
Day 126	125 [a]	127 [ab]	130 [b]	128 [ab]	2.8	0.02
			Average daily gain, kg/day			
[1]Day 1-14	0.39 [a]	0.42 [ab]	0.44 [b]	0.44 [b]	0.01	0.01
Day 14-35	0.69 [a]	0.70 [a]	0.75 [b]	0.72 [ab]	0.01	0.04
Day 35-56	1.02	1.00	1.00	0.98	0.02	0.85
Day 56-98	1.15	1.08	1.12	1.13	0.02	0.20
Day 98-126	0.87 [a]	1.06 [b]	1.07 [b]	0.98 [ab]	0.06	0.01
[2]Day 1-126	0.91 [a]	0.93 [ab]	0.96 [b]	0.94 [ab]	0.02	0.05
			Average daily intake (kg/day, DM basis)			
Day 1-14	0.70	0.66	0.69	0.69	0.02	0.55
Day 14-35	1.35	1.36	1.41	1.35	0.03	0.56
Day 35-56	2.14 [a]	1.85 [b]	1.90 [b]	1.88[b]	0.05	0.01
Day 56-98	3.10 [a]	2.62 [b]	2.67 [b]	2.70 [b]	0.07	0.01
Day 98-126	3.59	3.33	3.38	3.35	0.77	0.11
Day 1-126	2.47 [a]	2.2 [b]	2.26 [b]	2.24 [b]	0.08	0.01
			Feed conversion efficiency (gain : feed intake (DM basis))			
Day 1-14	0.48 [a]	0.55 [b]	0.56 [b]	0.55 [b]	0.01	0.01
Day 14-35	0.45	0.45	0.47 [b]	0.47	0.01	0.44
Day 35-56	0.42 [a]	0.48 [b]	0.46 [b]	0.45 [b]	0.01	0.01
Day 56-98	0.33	0.37	0.37	0.37	0.01	0.07
Day 98-126	0.21 [a]	0.28 [b]	0.28 [b]	0.25 [b]	0.01	0.01
Day 1-126	0.33 [a]	0.37 [b]	0.38 [b]	0.37 [b]	0.01	0.01

[1]Days on trial with in phase, [2]average of the whole trial period, [ab,] Means within a row without common letters differ ($P \leq .05$). Pigs were 18 ± 3 d old before at start of trial.

Table 3.5 Effects of dietary treatments on carcass characteristics and blood urea nitrogen

	Dietary treatment					
Carcass characteristics	20% [1]DDGS	20% [2]WDG	17% WDG + 3% CDS[3]	14% WDG + 6% CDS	SEM	*P* Value
Dressing (%)	74.1	73.62	72.99	73.24	0.42	0.41
Fat depth (mm)	21.51	20.11	21.35	21.82	0.52	0.34
Loin depth (mm)	70.77	70.51	71.98	71.85	0.62	0.43
Lean (%)	54.78	55.08	55.02	54.88	0.15	0.59
Blood urea nitrogen (mg/dL)	12.42	11.95	14.08	13.64	1.34	0.62

[1]DDGS = distillers dried grains with solubles
[2]WDG = wet distillers grains
[3] CDS = condensed distillers solubles

Table 3.6 Effects of dietary treatments on water intake (l/d)

	Dietary treatment					
Phases	20% DDGS[1]	20% WDG[2]	17% WDG + 3% CDS[3]	14% WDG + 6% CDS	SEM	$P_{(\text{Value})}$
*D(0-14)	12.33	13.21	14.9	8.59	3.95	0.72
D(14-35)	12.16	13.9	17.43	11.79	2.62	0.58
D(36-56)	13.13	13.82	17.25	16.6	2.69	0.76
D(56-98)	14.33	15.16	17	16.41	2.84	0.68
D(98-126)	15.23	12.81	16.87	17.62	3.14	0.61
Overall	13.44	13.78	16.69	14.2	2.23	0.73

*Days of trials with in one phase

[1]DDGS = distillers dried grains with solubles

[2]WDG = wet distillers grains

[3] CDS = condensed distillers solubles

Chapter 4

Summary

Liquid feeding is an alternative feeding strategy to dry feeding. It can use co-products from food industries, milk processing, and candy, bakery and ethanol industries. There are several advantages of feeding pigs in liquid form as compared to dry form, such as improved gut health, use of inexpensive co-products from the food and bio-fuel industry, flexibility and ease of feed delivery, and manipulation of feeding value of ingredients with enzymes and microbial inoculants (Scholten et al., 1999; Brooks et al., 2001; Van Winsen et al., 2001). Liquid feeding had been very popular in Europe, where they use wheat and barley as basal diet. More than 30% pig farms in Europe employ automatic liquid feeding systems (Brooks, 2001).

In the past decades liquid feeding has been gaining interest in North America. In Ontario, Canada for example 20% of grow to finish pigs are raised on liquid feeding (SLF, 2007). Based on the established facts of liquid feeding, two experiments were done to assess the advantage of liquid feeding under US conditions, where there are abundant liquid products from ethanol industries. In the US the ethanol co-products are corn based unlike the European condition. The experiments were conducted to explore advantages of these ethanol co-products in automated liquid feeding system. The first experiment was done to evaluate the nutritional composition and digestibility of energy and nutrients in these co-products. Results showed that these co-products have comparable digestibility values which could be of economic value to swine production. The second experiment was done to determine the level of WDG to CDS in growth performance and carcass characteristics in wean to finish pigs. Results show that a mixture of 17% WDG and 3% CDS showed better performance compared to the control. Over all pigs fed on these co-products showed good performance.

Literature cited

AOAC. 2000. Official Methods of Analysis. 17 ed. Assoc. Off. Anal. Chem. Gaithersburg, MD.

Adams, M., Mitchell R. 2002. Fermentation and pathogen control: a risk assessment approach. Int. J. Food Microbiol. 9:75-83.

Achi, O. K. 2005. The potential for upgrading traditional fermented foods through biotechnology. African Journal of Biotechnology 4(5), 375-380.

Anugwa, O. L. F., V.H. Varel, J. S. Dickson, W. G. Pond, and L. P. Krock. 1989. Effects of Dietary Fiber and Protein Concentration on Growth, Feed Efficiency, Visceral Organ Weights and Large Intestine Microbial Populations of Swine. J. Nutr. 879:886

Baidoo, S. K. X. Yang. J. Jendza, and D. Hanson D. 2014. Effects of condensed distiller's solubles to wet distiller's grains ratio on the growth performance and carcass characteristics of growing-finishing pigs. In ADSA-ASAS Midwest Meeting. Asas.

Bolarinwa, O. A., & Adeola, O. 2012. Direct and regression methods do not give different estimates of digestible and metabolizable energy of wheat for pigs. J. Anim. Sci. 90 (Supplement 4), 390-392.

Baldawin, R. L., Smith, N. E., Taylor, J. & Sharp, M. 1980 Manipulating metabolic parameters to improve growth rate and milk secretion. J. Anim. Sci. 51: 1416-1428.

Barber, J., Brooks, P. H. and Carpenter, J. L. 199l. The effect of four levels of food on the water intake and· water to food ratio of growing pigs. Animal Production, 52, 602 (Abstr.).

Barber J. 1992. The rationalization of drinking water supplies for pig housing [PhD thesis]. (UK): Polytechnic South West.

Bark, L. J., Crenshaw, T. D. and Leibbrandt, V.D. 1986. The effect of meal intervals and weaning on feed intake of early weaned pigs. J. Anim. Sci. 62:1233–1239.

Big Dutchman. 2012. Pig feeding systems. http://www.bigdutchman.de/en/pig-production/home.html (accessed March 5, 2013).

Braude, R. 1972. Feeding methods. In: Cole, D.J.A. Pig Production. Butterworths, London. 279-291.

Braude, R. and Newport, M. J. 1977. A note on a comparison of two systems for rearing pigs weaned at 2 days of age, involving either a liquid or a pelleted diet. Animal Production, 24, 271 - 274.

Braun, K. and K. de Lange. 2004. Liquid swine feed ingredients: Nutritional quality and contaminants. Proc. ANAC Eastern Nutrition Conference, May 11-12, 2004, Ottawa, Ontario, Canada. 17 pp.

Brooks, P. H., Moran, C. A., Beal, J. D., Demeckova, V. and; Campbell, A. 2001. Liquid Feeding for the young piglet, In: Varley, M. and Wiseman, J. BSAS Occasional Publication- The Weaner Pig. CABl International, Nottingham.

Brooks, P. H., Geary, T. M., Morgan, D. T. and Campbell, A. 1996.New developments in liquid feeding. The Pig Journal, 36, 43-64.

Brooks, P.H. and Carpenter, J.L. (1990). The water requirement of growing–finishing pigs; theoretical and practical considerations. In: Recent Advances in Animal Nutrition 1990, pp. 115–136 (eds. W. Haresign and D.J.A. Cole), Butterworths, London.

Brooks, P. H. 1999. The potential of liquid feeding systems. In: Lyons, T.P. and Cole, D.J.A. Concepts in Pig Science. Nottingham University Press, Nottingham. 81- 98.

Brooks, P. H., Moran, C. and Beal, J. D. 1999. Liquid feeding of pigs: Potential for reducing environmental impact and for improving productivity and food safety. In:

Brooks, P. H., J. D. Beal, and S. Niven. 2001. Liquid feeding of pigs: potential for reducing environmental impact and for improving productivity and food safety. Recent advance in Animal Nutrition in Australia. 13:49-63.

Brooks P. H. 2003. Liquid feeding as a means to promote pig health. London Swine Conference maintaining your competitive Edge, 9-10 April 2003, p. 83-103.

Brooks P. H, C. A. Tsourgiannis. 2003. Weaning the pig, concepts and consequences. Pluske, J. R, J. Le Dividich, M. W. A Verstegen. (Eds.). Wageningen Academic Publishers, Wageningen, The Netherlands. Factors affecting the voluntary feed intake of the weaned pig. p. 81-116.

Brooks, P. H., J. D. Beal, S. Niven. 2003a. Liquid feeding of pigs I. Potential for reducing environmental impact and for improving productivity. In: Animal Science Papers and Reports. Presented at the Conference: Effect of Genetic and Non-genetic Factors on Carcass and Meat Quality of Pigs; 24–25 April 2003; Siedlce, Poland. Vol 21, Supplement 1, 7-22.

Brooks, P. H. 2008. Fermented liquid feed for pigs. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 3, 73, pp. 18.

Canibe, N., Højberg, J. H. Badsberg , O.B.B. Jensen. 2007. Effect of feeding fermented liquid feed and fermented grain on gastrointestinal ecology and growth performance in piglets. J. Anim. Sci. 85:2959-2971.

Canibe, N., B.B. Jensen. 2003. Fermented and non-fermented liquid feed to growing pigs: effect on aspects of gastrointestinal ecology and growth performance. J Anim Sci. 81, 2019-2031.

Canibe, N., Jensen BB. 2011. Fermented liquid feed-Microbial and nutritional aspects and impact on enteric diseases in pigs. Anim. Feed. Sci. Tech. 173, 17– 40.

Chen, H. Y., A. J. Lewis, P. S. Miller, and J. T. Yen. 1999. The effect of excess protein on growth performance and protein metabolism of finishing barrows and gilts. J. Anim. Sci. 77:3238.

Choct, M. Selby, E. A. D. Cadogan. D. J. & Campbell. R. G. 2004a. Effect of liquid to feed ratio, steeping time, and enzyme supplementation on the performance of weaner pigs. Australian Journal of, Agricultural Research 55(2), 247-252.

Columbus, D., J. Zhu, D. Woods, J. Squire, E. Jeaurond, and C. F. M. de Lange. 2006. On-farm experience with swine liquid feeding: research unit at Arkell Swine research station at the University of Guelph. Pages 189-198 in Proc. 2006. London Swine Conference, London, Ontario, Canada (www.londonswineconference.ca).

Cranwell, P.D., Noakes, D.E. and Hill, K.J. 1976. Gastric secretion and fermentation in the suckling pig. Br. J. Nutr. 36, 71–86.

de Haas, T.C.M. 1998. Home mix farming with food industry co–products: experience in the Netherlands and its worldwide possibilities. In: Biotechnology in the Feed Industry — Proceedings of Alltech’s 14th Annual Symposium, pp. 613–618 (eds. T.P. Lyons and K. Jacques), Nottingham University Press, Nottingham.

de Lange, C. F. M., C. H. Zhu. 2012. Liquid feeding corn-based diets to growing pigs: practical considerations and use of co-products. In Patience, J. F. Feed efficiency in swine. The Netherlands. Wageningen Academic Publishers.

de Lange, C. F. M., C. H. Zhu, S. Niven, D. Columbus, and D. Woods. 2006. Swine liquid feeding: Nutritional considerations. Western Nutrition Conference, Winnipeg, MB, Canada.

de Lange, C.F.M., C.H. Zhu, and S.J. Niven. 2007. Effective application of enzymes and microbes to enhance the nutritional value of pig feed ingredients: a case for liquid feeding. 2007. Alltech symposium. May 22-23, 2007. Kentucky, Lexington, USA. pp 33-40

Deprez P, Deroose P, Van den Hende C, Muylle E, Oyaert W. 1987. Liquid versus dry feeding in weaned piglets: the influence on small intestinal morphology. J Vet med. 34:254-259.

Eggum, B. O. 1970. Blood urea measurement as a technique for assessing protein quality. Br. J. Nutr. 24:983-988.

European Food Safety Authority (EFSA). 2006. Opinion of the scientific panel on biological hazards on the request from the Commission related to the public health risks of feeding farmed animals with ready to use dairy products without further treatment. EFSA J. 340:1-58.

English, P. R., Fowler, V. R., Baxton, S. and Smith, B. 1996.The Growing and Finishing Pig: Improving Efficiency. Farming Press Books, Ipswich. 2nd, ed.

Erickson, G.E, T.J. Klopfenstein and A.K. Watson 2012. Utilization of feed co-products from wet or dry milling for beef cattle. In Makkar, H.P.S, Biofuel co-products as livestock feed (pp. 175-207). Rome, Italy. FAO.

Farzan, A., Friendship, R.M., Dewey, C.E., Warriner, K., Poppe, C. and Klotins, K. 2006. Prevalence of salmonella spp. on Canadian pig farms using liquid or dry-feeding. Prev Vet Med 73:241-254

Fontaine, J., U. Zimmer, P. J. Moughan, and S. M. Rutherfurd. 2007. Effect of heat damage in an autoclave on the reactive lysine contents of soy products and corn distillers dried grains with solubles. Use of the results to check on lysine damage in common qualities of these ingredients. J. Agric. Food Chem. 55:10737-10743.

Firkins, J. L., L. L. Berger, and G. C. Fahey, Jr. 1985. Evaluation of wet and dry distiller's grains and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. 60:847

Fontaine, J., U. Zimmer, P. J. Moughan, and S. M. Rutherfurd. 2007. Effect of heat damage in an autoclave on the reactive lysine contents of soy products and corn distillers dried grains with solubles. Use of the results to check on lysine damage in common qualities of these ingredients. J. Agric. Food Chem. 55:10737-10743.

Ham, G. A., , R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distiller's byproducts compared with dried corn distiller's grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246–3257.

Geary, T. M., P.H. Brooks, Morgan, D. T., A. Campbell, and P.J. Russell. 1996. Performance of weaner pigs fed ad libitum with liquid feed at different dry matter concentrations. Journal of Science of Food and Agriculture, 12, 17-24.

Geary, T.M. and Brooks, P.H. 1998. The effect of weaning weight and age on the post weaning growth performance of piglets fed fermented liquid diets. The Pig Journal 42, 10–23.

Geary TM, Brooks PH, Beal JD, Campbell A. 1999. Effect on weaner pig performance and diet microbiology of feeding a liquid diet acidified to pH 4 with either lactic acid or through fermentation with Pediococcusacidilactici. J. Sci Food. Agr. 79:633-640.

Gill, B. P., P.H. Brooks, and J. L. Carpenter. 1987. Voluntary water use by growing pigs offered a liquid feed of differing water to meal ratios. In: Smith, A.T. and Lawrence, T.L.J. Pig housing and the environment. British Society of Animal Production, Edinburgh, U.K. Occasional publication No. 11, ed. 1-2.Jensen, B.B. (1998). The impact of feed additives on the microbial ecology of the gut, in young pigs. Journal of Animal and Feed Sciences 7, 45–64.

Goodson, J., and J. F. Fontaine. 2004. Variability in DDGS from ethanol plants. Feed Manage. 55:20–25

Hillman, K., Hunt, B., Davies, R. and Gill, B.P. 2004. The microbial status of the pig and its environment under different housing and feeding systems: 1. Liquid versus dry feeding in fully slatted and straw bedded housing. In Proc British Society of Animal Science Annual Meeting, York, March 2004, p 44.

Jensen, B.B. and. Mikkelsen, L.L. (1998). Feeding liquid diets to pigs. In: P. C. Garnsworthy and J. Wiseman (ed.) *Recent Advances in Animal Nutrition*. p 107. Nottingham University Press, Nottingham, UK.

Jensen, B. B. 1998. The impact of feed additives on the microbial ecology of the gut in young pigs. J. Anim. Feed Sci. 7: 45-64.

Johnston, L., G. Shurson, and J. Goihl. 2007. Additives to improve flowability of DDGS studied. National Hog. Farmer. http://nationalhogfarmer.com/nutrition/ingredients/additives-improve-flowability-ddgs (Accessed on Dec 7, 2013)

Kerr, B. J., F. K. McKeith, and R. A. Easter. 1995. Effect on performance and carcass characteristics of nursery to finisher pigs fed reduced crude protein, amino acid-supplemented diets. J. Anim. Sci. 73:433-440.

Kim, J. H., K. N. Heo, J. Odle, I. H. Han, and R. J. Harrell. 2001. Liquid diets accelerate the growth of early-weaned pigs and the effects are maintained to market weight. J. Anim. Sci. 79:427-434.

Kingsly, A. R. P., Ileleji, K. E., Clementson, C. L., Garcia, A., Maier, D. E., Stroshine, R. L., et al. 2010. The effect of process variables during drying on the physical and chemical characteristics of corn dried distiller's grains with solubles (DDGS) - plant scale experiments. Bioresource Technology, 101,193-199.

Kinman, L.A., Hilton, G.G., Richards, C.J., Morgan, J.B., Krehbiel, C.R., Hicks, R.B., Dillwith, J.W., VanOverbeke, D.L., 2011. Impact of feeding various amounts of wet and dry distiller's grains to yearling steers on palatability, fatty acid profile, and retail case life of longissimus muscle. J. Anim Sci. 89, 179-184.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. Board-invited review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86: 1223-1231.

Klopfenstein, T.J., Erickson, G.E., Bremer, V.R., 2007. Feeding Corn Milling Byproducts to feed lot Cattle. Veterinary Clinics of North America: Food Animal Practice 23, 223-245.

Klopfenstein, T. 1996. Distillers grains as an energy source and effect of drying on protein availability. Animal Feed Science and Technology 60, 201-207.

Kneale, W. A. 1971. A comparison of commercial wet and dry feeding systems for fattening bacon pigs. Experimental Husband. **21,** 51-59.

Kornegay, E.T., D. Rhein-Welker, M.D. Lindemann and C.M. Wood. 1995. Performance and nutrient digestibility in weanling pigs as influenced by yeast culture additions to starter diets containing dried whey or one of two fiber sources. J. Anim. Sci. 73:1381-1389.

Kornegay, E. T., Rhomas, H. R., Handlin, D. L., Noland, P. R. and Burbank, D. K. 1981. Wet versus dry diets .for weaned pigs. Journal of Animal Science, 52, (1), 14-17.

Koong, L. J., C. L. Ferrell, and J. A. Nienaber. 1985. Assessment of interrelationships among levels of intake and production, organ size and fasting heat production in growing animals. J. Nutr. 115:1383-1390.

Krebs, H. A. 1942. Urea formation in mammalian liver. Biochem. J. 36:758-767.

Lalles, J., P. Bosi, H. Smidt, and C. R. Stokes. 2006. Weaning: A challenge to gut physiologists. Live St. Sci.108:82-93.

Lawlor, P. G, and B.P. Lynch. 1999. Comparison between wet and dry feeding for group fed first stage pigs. J. Anim Sci. 77 (Suppl. 1), 186.

Lawlor P. G, P.B. Lynch, G.E. Gardiner, P.J. Caffrey, J.V. O'Doherty. 2002. Effect of liquid feeding weaned pigs on growth performance to harvest. J Anim Sci. 80:1725-1735.

Lecce, J. G., Armstrong, W. D., Crawford, P.C. and Ducharme, G. A. 1979. Nutrition and management of early weaned piglets; liquid vs dry feeding. J Anim. Sci. 48: 1007.

Lehninger, A. L., D. L. Nelson, and M. M. Cox. 2005. Lehninger principles of biochemistry. 4th ed. WH Freeman & Co. NY.

Liptrap, D. O., and M. G. Hogberg. 1992. Physical forms of feed: Feed processing and feeder design and operation. In: Millet, E.R., Ullcey, D.E. and Lewis, A.J. Swine Nutrition. Butterworth-Heinemann, London, UK. 373.-392.

Loy, D.D., D.R. Strohbehn. 2007. Ethanol co-products for cattle: factors affecting the economics of corn co-products in cattle feed. Iowa Beef Center, IBC-28. Iowa State University Extension.

McCracken, B.A., Gaskins, H.R., Ruwekaiser, P.J., Klasing, K.C. and Jewell. D.E. 1995. Diet-dependent and diet- independent metabolic responses underlie growth stasis of pigs at weaning. J. Nutr. 125:2838-2845

McDonald, D. E., D. W. Pethick, B. P. Mullan, and D. J. Hampson. 2001. Increasing viscosity of the intestinal contents alters small intestinal structure and intestinal growth, and stimulates proliferation of enterotoxigenic escherichia coli in newly-weaned pigs. Br. J. Nutr. 86:487-498.

Meat and Livestock commission (MLC). 2005. Finishing pigs – systems research. Final report to defra. August 2005. British Pig Executive, Stoneleigh Park, Kenilworth, Warwickshire, CV8 2TL, UK

MLC. 2004.Finishing Pigs: Systems Research. Production Trial 1 Dry versus liquid feeding in two contrasting finishing systems (fully slatted versus straw based housing). Meat and Livestock Commission, Milton Keynes, UK

Näsi, M. 1985. Distillers feed from various grains as protein sources for pigs. J. Agric. Sci. Finl. 57:255-262.

Niven, S. J, J.D. Beal , P. H. Brooks. 2006. The effect of controlled fermentation on the fate of synthetic lysine in liquid diets for pigs. Anim Feed Sci Technol. 129:304-315.

Niven, S. J., C. Zhu, D. Columbus, O. Izquirde Scholtenand C.F.M. de Lange. 2006c. Chemical composition and phosphorus release of corn steep water during phytase steeping. J. Anim. Sci. 84 (suppl. 1; Abstracts).

Noblet J, J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389–3398.

Nout, M.J.R., Rombouts, F.M., Havelaar, A., 1989. Effect of accelerated natural lactic fermentation of infant food ingredients on some pathogenic microorganisms. Int. J. Food Microbiol. 8, 351–361.

NRC, 2012. Nutrient Requirements of Swine. 11th rev. Ed. Natl. Acad. Press, Washington. DC. Pages 127 – 156.

Olstorpe, M, K., J. E. Lyberg, J. S. Lindberg, V. Passoth. 2008. Population diversity of yeasts and lactic acid bacteria in pig feed fermented with whey, wet wheat distillers' grains, or water at different temperatures. Appl. Environ. Microb. 74:1696-1703.

Pahm, A. A., C. Pedersen, D. Hoehler, H. H. Stein. 2008. Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 86:2180–2189.

Patterson DC. 1989. A comparison of various feeding systems for finishing pigs. Anim. Feed Sci. Tech. 26:251-260.

Partridge, G. G, J. Fisher, H. Gregory, S. G Prior. 1992. Automated wet feeding of weaner pig versus 807 conventional dry diet feeding: effects on growth rate and food consumption. Anim Prod. 54: 484.

Partridge, G., and B. P. Gill. 1993.New approaches with pig weaner diets. In: Gamsworthy, P.C. and Cole, D.J.A. Recent Advances in Animal Nutrition. Nottingham University Press, Nottingham. 221-248.

Partridge, G. G., J. Fisher, H. Gregory, and S. G Prior. 1992. Automated wet feeding of weaner pigs versus conventional dry feeding: Effects on growth rate and food consumption. Animal Production, 54, 484.

Pedersen, A. 0., Fisker, B. N., Hansen, C. F. and Kjeldsen, N. J. 1998, Liquid feed for growing-finishing pigs under Danish conditions. 49th Annual Meeting of the European Association for Animal Production, Warsaw, Poland. 1-4.

Pedersen C, S. Roos, H. Johnsson, J. E. Lindberg. 2005. Performance, feeding behavior and microbial diversity in weaned piglets fed liquid diets based on water or wet wheat distiller's grain. Arch. Anim. Nutr. 59:165-179.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007a. Digestibility of energy and phosphorus in 10 samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Plumed-Ferrer C, I. Kivelä, P. Hyvönen, A. Von Wright. 2005. Survival, growth and persistence under farm conditions of a Lactobacillus plantarum strain inoculated into liquid pig feed. J. Appl. Microbiol. 99:851-858.

Plumed-Ferrer, C., and A. Von Wright. 2008. Fermented pig liquid feed: nutritional, safety and regulatory aspects Journal of Applied Microbiology 106: 351–368, REVIEW ARTICLE

Pluske, J. R., I. H. Williams, and F. X. Aherne. 1996a. Maintenance of villous height and crypt depth in piglets by providing continuous nutrition after weaning. Animal Science, 62, 131-144.

Pluske, J. R., Williams, I. H. and Aherne, F. X. 1996b.Villous height and crypt depth in piglets in response to increases in the intake of cows' milk after weaning. Animal Science, 62, 145-158.

Pluske, J. R, D. J. Hampson, I. H. Williams. 1997. Factors influencing the structure and function of the small intestine in the weaned pig: a review. Live St. Prod. Sci. 51:215-236.

Ramirez, E.C., D. B Johnston, A. J. McAloon, W. Yee, V. Singh. 2008. Engineering process and cost model for a conventional corn wet milling facility. Industrial Crops and Products, 27, 91-97.

RFA. 2007. Ethanol Industry Outlook. Renewable Fuels Association, Washington, DC. http://ethanolrfa.org/page/-/objects/pdf/outlook/RFA_Outlook_2007.pdf?nocdn=1 (accessed March 6, 2014).

Ruis, G. 2003. Emerging technologies in swine liquid feeding. Proceedings Swine Liquid Feeding Association. March 4, 2003. Stratford, ON, Canada.

Rosentrater, K.A., E. Kongar. 2009. Modeling the effects of pelleting on the logistics of distillers grains shipping. Bioresource Technology 100, 6550-6558

Russell, J. B., and F. Diez-Gonzales. 1998. The effects of fermentation acids on bacterial growth. Adv. Microb. Physiol. 39, 205–234.

Russell, P. J., T. M. Geary, P. H. Brooks, and A. J. Campbell. 1996. Perfom1ance, water use and effluent output of weaner pigs fed ad libitum with either dry pellets or liquid feed and the role of microbial activity in the liquid feed. Journal of Science of Food and Agriculture, 72, 8-16.

Sampson, E. J., M. A. Baird, C. Burtis, E. M. Smith, D. Witte, and D. D. Bayse. 1980. A coupled-enzyme equilibrium method for measuring urea in serum: Optimization and evaluation of the AACC study group on urea candidate reference method. Clin. Chem. 26:816-826.

Scott, K., Chennells, D. J., D. Armstrong, L. Taylor, B. P. Gill, and S. A Edwards. 2007. The welfare of finishing pigs under different housing and feeding systems: Liquid versus dry feeding in fully-slatted and straw based housing. Anim. Welfare, 16:53-62.

Scholten, R. H. J., C. M. C. V. D. Peet-Schwering, M. W. A. Verstegen, L. A. Hartog, Schrama, J. W. and Vesseur, P. C. 1999. Fermented co-products and fermented compound diets for pigs: A review. Animal Feed Science and Technology, 82, 1-19.

Scholten .R. H. J, C. M. C. V. D. Peet-Schwering, L. A den Hartog, M. Balk, J.W. Schrama, W. M. A. Verstegen. 2002. Fermented wheat in liquid diets: Effects on gastrointestinal characteristics in weanling piglets. J. Anim. Sci. 80:1179-1186.

Singh, V. J., Rausch, K. D., Yang, P., Shapouri, H., Belyea, R. L., & Tumbleson, M. E. 2001. Modified dry grind ethanol process. Public. No. 2001e7021. Urbana, IL: University of Illinois at Urbana-Champaign.

Soares, J. A. H. H. Stein, V. Singh, G. Shurson, and J. E. Pettigrew. 2012. Amino acid digestibility of corn distillers dried grains with solubles, liquid condensed solubles, pulse dried thin stillage, and syrup balls fed to growing pigs. J. Anim. Sci. 90:1255-1261.

Shurson, G.C. R. T. Zijlstra, B. J Kerr, and H. H. Stein 2012. Feeding biofuels co-products to pigs. In Makkar, H.P.S, Biofuel co-products as livestock feed (pp. 175-207). Rome, Italy. FAO

Shurson, G. C., and A. S. Alghamdi. 2008. Quality and new technologies to create corn co-products from ethanol production. Pages 231-259 in Babcock, B. A., D. J. Hayes, and J. D. Lawrence (Eds): Using distillers grains in the US and international livestock and poultry industries. Midwest Agribusiness Trade Research and Information Center. Iowa State University, Ames, IA.

Shurson, G. 2006. What We Know About Feeding Liquid By-Products to Pigs. University of Minnesota, USA. http://www.ddgs.umn.edu/prod/groups/cfans/@pub/@cfans/@ansci/documents/asset/cfans_asset_416206.pdf. (Accessed date oct. 04, 2013).

Shurson, G. 2004. Nutritional and value added benefits of feeding maize DDGS and other dry mill co-products to swine. Pre-conference Symposium. 40th Eastern Nutrition Conference. Animal Nutrition Association of Canada, Ottawa, ON K1N 7G2 Canada.

Smith P. 1976. A comparison of dry, wet and soaked meal for fattening bacon pigs. Exper. Husbandry. 30:87-94.

Søndergaard. E, N. O. Nielsen, N. Ingemann, K. Stefanek. 2012. Aarhus University, Denmark. Optimizing PDGS from bio-ethanol production. http://www.regionmidtjylland.dk/files/Regional%20udvikling/Energi/Ny/Projektbeskrivelser/Bioraffinaderi%20til%20produktion%20af%20bioenergi%20i%20RM/Hovedrapport%20-%20Optimising%20PDGS%20from%20the%20Bioethanol%20Production.pdf (Accessed may 14, 2014).

Smith, N. E. 1970. Quantitative Simulation Analyses of Ruminant Metabolic Functions: Basal; Lactation; Milk Fat Depression, Ph.D. thesis, University of California, Davis.

Squire, J. M. 2005. Fermentation of an alternative feedstuff for use in swine liquid feeding. M.Sc. Thesis. Department of Animal and Poultry Science University of Guelph. Guelph, ON, Canada.

Squire, J. M., C. Zhu, and C. F. M. de Lange. 2004. Fermentation of an alternative feedstuff for us in swine liquid feeding: Condensed corn distillers solubles. Can. J. Anim. Sci. 84 (Abstracts):782.

Swine Liquid Feeding Association (SLFA). 2007. www.slfa.ca (Access date, Oct, 4, 2013)

Smith, P. 1976. A comparison of dry, wet and soaked meal for fattening bacon pigs. Experimental Husbandry, 30, 87-94.

Spiehs, M. J., Whitney, M. H., and G. C. Shurson. 2002. Nutrient database for distiller's dried grainswith solubles produced from new ethanol plants in Minnesota and South Dakota. J Anim Sci. 80:2639–2645.

Stein, H. H., B. Seve, M. F. Fulle, P. J. Moughan, C. F. M. de Lange. 2007. Invited review: amino acid bioavailability and digestibility in pig feed ingredients: terminology and application. J. Anim. Sci. 85:172–180.

Stein, H. H, G. C. Shurson. 2009. The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292–1303.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. Anim. Sci. 77: V-12.

Stock, R., and T. Klopfenstein. 1982. Feeding value of distillers grains for ruminants. In: R. A. Parsons (Ed.) Feed and Fuel from Ethanol Production Symposium. Northeast Regional Agric. Engineering Service Publ. 17. Ithaca, NY.

Tielen, M. J. M., van Schie, F. W., van der Wolf, P. J., Elbers, A. R. W, Koppens, J. M. C. C. and Wolbers, W. B. 1997. Risk factors and control measures for subclinical salmonella infection in pig herds. In: Bech-Nielsen, S. and Nielsen, J.P. Proceedings of the Second International Symposium on Epidemiology and Control of Salmonella in Pork: Copenhagen, Denmark, August 20-22. Federation of Danish Pig Producers and Slaughterhouses, Copenhagen.32-35.

Upton, P. 1993. Breaking the appetite barrier. P. Upton, Marketing Consultancy.

Van der Wolf, P. J., W. B. Wolbers, A. R. W. Elbers, H.M.J.F . Van Der Heijden, J.M.C.C. Koppen, W.A. Hunneman, F.W. Van Schie, and M. J. M. Tielen. 2001. Herd level husbandry factors associated with the serological Salmonella prevalence in finishing pig herds in The Netherlands. Vet. Microbio. 78:205-219.

Van Heugten, E., D.W. Funderburke and K.L. Dorton. 2003. Growth performance, nutrient digestibility, and fecal microflora in weanling pigs fed live yeast. J. Anim. Sci. 81:1004-1012.

Van Winsen .R. L, L. J. A. Lipman, S. Biesterveld, B. A. P. Urlings, J. M. A. Snijders, F. Van Knapen. 2000. Mechanism of Salmonella reduction in fermented pig feed. J. Sci. Food Agr. 81:342-346.

Van Winsen, R. L, B. A. P. Urlings, L. J. A. Lipman, J. M. A. Snijders, D. Keuzenkamp, J. H. M. Verheijden, F. Van Knapen. 2001. Effect of fermented feed on the microbial population of the gastrointestinal tracts of pigs. Appl Environ Microb. 67:3071-3076.

Van Winsen, R. L., L. J. A. Lipman, S, Biesterveld, B.A.P. Urlings, J. M. A. Snijders, F. Van Knapen. 2001a. Mechanism of Salmonella reduction in fermented pig feed. J. Sci. Food Agric. 81, 342–346.

Van Winsen, R.L., B.A.P. Urlings, L.J.A. Lipman, J. M. A. Snijders, D. Keuzenkamp, J. H. M. Verheijden, F. Van Knapen. 2001b. Effect of fermented feed on the microbial population of the gastrointestinal tracts of pigs. Appl. Environ. Microbiol. 67, 3071–3076.

Weiss, B., M. Eastridge, D. Shoemaker, and N. St-Pierre. 2007. Distillers grains. Ohio State University Extension. http://ohioline.osu.edu/as-fact/pdf/distillers.pdf (Accessed Nov 10, 2013).

Whittemore, C. T., and Green, D. M. 2001. Growth of the young weaned pig. Varley, Ma; Wiseman, J. The weaner pig nutrition and management. Nottingham: CAB, 1-15.

Appendix

Table 4.1 Average amount of doses given to pigs before slaughter

Diet	BW (kg)	Telazol (mg/kg)	Na Pentobarbital (mg/kg)
100%CSBM[1]	129.33	3.50	7.00
15%WDG[2]	129.83	2.67	8.50
30%WDG	129.33	2.83	8.00
15%CDS[3]	126.33	2.58	6.33
30%CDS	127.50	3.17	6.33
15%WDG+15%CDS	132.00	2.58	7.17

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles

Table 4.2 Performance study room temperature range

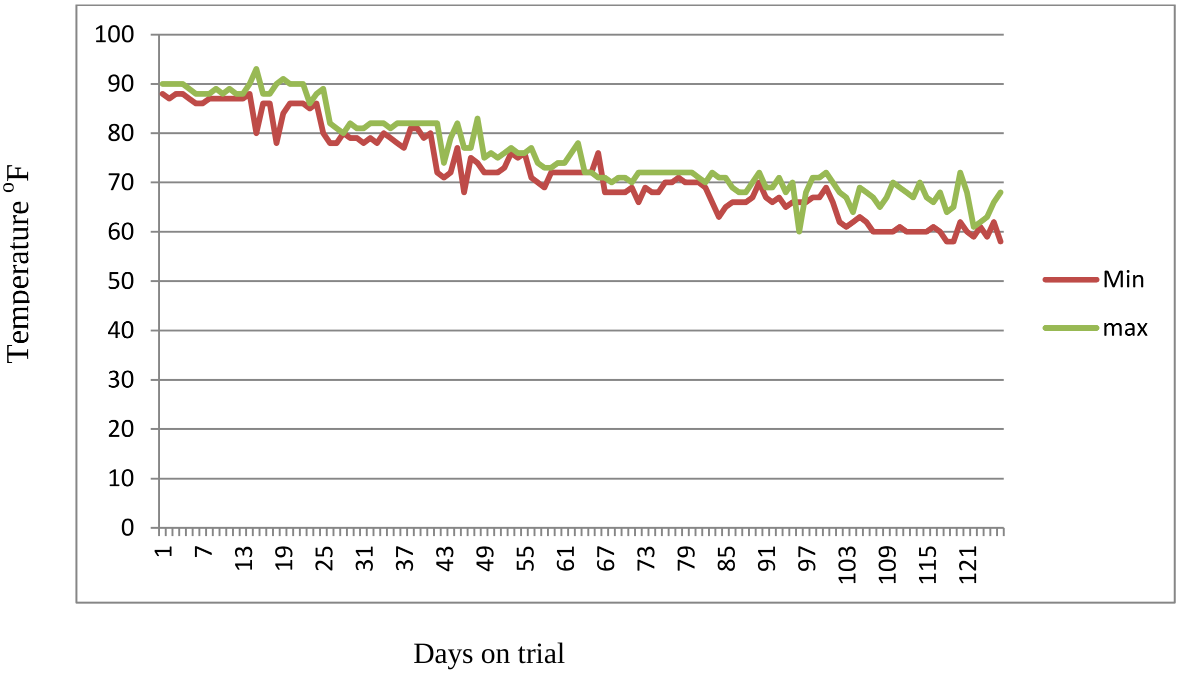

Table 4.3 Effect of dietary treatment diets on organ weights and intestinal length

Item	100% CSBM[1]	15% WDG[2]	30% WDG	15% CDS[3]	30% WDG	15% WDG+ 15% CDS	SEM	P (Value)
Stomach weight (kg)	0.40	0.46	0.44	0.41	0.40	0.443	0.02	0.05
Liver weight (kg)	1.20	1.41	1.36	1.44	1.45	1.413	0.12	0.69
Kidney weight (kg)	0.29	0.28	0.28	0.31	0.26	0.3	0.29	0.39
Spleen weight (kg)	0.21	0.19	0.11	0.16	0.22	0.165	0.03	0.06
Intestine length (m)	16.36	15.81	15.19	14.78	15.29	15.848	0.58	0.45

[1]CSBM = corn soybean-meal
[2]WDG = wet distillers grain
[3]CDS = condensed distillers solubles